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of the
37th Southern Pasture and Forage Crop Improvement Conference

May 19-22, 1980
Nashville, Tennessee

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OF THE

37th SOUTHERN PASTURE AND FORAGE CROP

IMPROVEMENT CONFERENCE

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INTRODUCTION

By R. D. Mochrie

It is a special privilege for me to give the introduction to this symposium in honor and memory of Curly Lucas. As far as I know, I am the only person to receive a doctorate in Animal Science at North Carolina State University who had Curly as a major professor. Dr. R. K. Waugh, who was my original graduate committee chairman, left within a year of my arrival in Raleigh to serve on our agricultural mission to Peru. Curly became my major advisor in Bob Waugh's absence.

I first met Curly at the Animal Science meeting in 1952. That was back when the meetings were held at the Hotel Sherman in Chicago on Friday and Saturday after Thanksgiving. It was a memorable occasion for me for several reasons: (1) I was giving my very first paper at a scientific meeting, (2) the room was hot and stuffy and a graduate student from Wisconsin passed out during his presentation, and (3) more significantly, Curly presented back-to-back papers in the Pasture, Forage, and Range Section.

Curly's papers were entitled "Magnitudes of Experimental Errors in Grazing Trials" and "Methods of Computing Results of Grazing Trials." His conclusions were that "pastures that will carry 1-3 animals appear to be of optimum size" and that "errors in the coefficients for converting gain and weight to TDN can have large effects on ETDN and etdn, but their effects on animal days and gain per acre will usually be negligible." That same year, a paper dealing with the interpretation of put-and-take grazing systems was published in detail by Mott and Lucas in the Proceedings of the VI International Grassland Congress.

Dr. Lucas had a long and distinguished career. Henry Laurence Lucas, Jr., was born in Pasadena, California, January 8, 1916. He was reared on a fruit and dairy ranch in Southern California before receiving a B.S. from the University of California at Davis in 1937 and a Ph.D. from Cornell in Animal Nutrition in 1943. His professional positions attest to the diversity of his interests and the range of his abilities. He was successively a Dairy Herd Improvement Association milk tester, a dairy cattle feed investigator, an instructor in animal physiology at the Cornell Veterinary School, a research associate in poultry nutrition, and a professor of experimental statistics. In the last 16 years of his life, he conceived, nurtured and directed the Biomathematics Program at North Carolina State University.

Dr. Lucas contributed in many ways (member, officer, committee chairman) to the 10 professional societies in which he held membership. These ranged from the Mathematical Association of America and the Institute of Mathematical Statistics to the American Society of Animal Science and the American Dairy Science Association. He was a Fellow of both the American Statistical Association and American Association of Advancement of Science. The academic, governmental, and industrial organizations which he served as committeeman, panelist, discussant, speaker, organizer, advisor and consultant were many and varied.

In addition to his professional societies, such groups included the National Research Council, National Institute of General Medical Science, Commission on Undergraduate Education in Biological Sciences, National Institutes of Health, Oak Ridge National Laboratory, U.S. Army, Dupont, Ralston Purina, and the Idaho Fish and Game Department. He co-authored White House reports entitled "Biomedical Science and Its Administration--A Study of NIH" and "Restoring the Quality of Our Environment."

He was probably best known to most of us as a speaker, writer, and statistical consultant. Curly authored or co-authored over 95 published articles and 30 miscellaneous papers. Among those best known to us were several on the effects of soils and weather on nutritional value of vegetables, "Design of Dairy Cattle Experiments," "Special Designs in Grazing Experiments," "Determination of Forage Yield and Quality from Animal Responses," "Some Theoretical Aspects of Estimating Forage Quality," "Formulation and Role of Input-Output Models in Animal Production," "A Model for Growth of Fermenting Microorganisms," and "Relations Between Digestibility and Composition of Feeds and Foods." This latter paper was the basis for a report in the Proceedings of our 16th Conference where the "Lucas Test" for a nutritive entity is outlined.

All of this scholarly effort led to his listing in seven or more Who's Who and Leaders-in-Science type publications. Last fall a very fitting memorial symposium entitled "Systems Concepts in Agriculture" was held on the Raleigh and Greensboro campuses of two of our North Carolina Universities. The dedicatory statement read as follows: "In memory of his vision and inspired leadership in advancing systems concepts in the study of Agricultural Science."

In spite of demanding professional obligations, Curly always was greatly devoted to his church work and to his family. He found much pleasure in socializing with his friends, enjoying his roles as a pigeon fancier, a fast-pitch softball pitcher, and one who could master the very latest in dancing fads.

Although heavily involved with research and administration of the Biomathematics Program, Curly never lost touch with teaching and always had time to discuss problems with his colleagues. This can be attested to by many in this room. I was always personally impressed by his patience with and understanding of his students, colleagues, and fellowmen.

Dr. Lucas died on June 8, 1977. It is fitting that this organization and those of us to whom he gave so much should honor his memory today with this symposium.

Symposium
Forage Evaluation in the 80's: The Legacy of Dr. H. L. "Curly" Lucas

MEASURING FORAGE QUANTITY AND QUALITY IN GRAZING TRIALS

By G. O. Mott

The present generation of forage-livestock specialists owes a great debt of gratitude to Dr. H. L. Lucas for his insight, his analytical approach to problem solving, and his ability to conceptualize solutions in mathematical terms. The topic which has been assigned to me is a subject to which "Curly" was giving considerable thought in the early 1950's when we first met. If any of you recognize some of the concepts which I shall discuss in this paper, it is no coincidence, since the framework was established many years ago by him and those who came under his influence.

FORAGE QUANTITY

To avoid confusion, certain terms should be defined. Forage available is the amount of forage present at the beginning of a time period plus that which is produced during the time period. Forage yield is the amount of forage recovered (consumed) by the grazing animals. A corollary to this is:

Consumption/animal x No. of animals/area = Forage yield/area.

It follows that yield can exceed current production but it cannot exceed forage available. In grazing trials we are frequently faced with the decision as to how much of the available forage should be utilized. The terms attempting to describe this concept are numerous. Such terms as carrying capacity, grazing capacity, grazing rate, stocking rate, use, use factor, proper use, degree of use, grazing pressure, and stocking pressure are found in the literature. The key to this situation seems to be to define carrying capacity as the stocking rate when grazing pressure and forage yield are at their optimum; neither overgrazing or undergrazing the pasture. The difficulty with this concept is that one must assume that the researcher has a preconceived idea of when the pasture is being overgrazed or undergrazed. In fact, he seldom knows the stocking rate which gives optimum forage yield, so he must consider stocking rate as both an experimental variable as well as a response variable. If the investigator is successful in stocking the pasture near its carrying capacity he then will have a good estimate of forage yield in terms of animals/area or animal days/area.

The perennial pasture ecosystem is probably more sensitive to overgrazing and undergrazing than is the animal which is grazing the pasture, at least in the long term. A corollary is that the animal can tolerate periods of low feed supply and recover rapidly during periods of abundance. It then follows that the

$$\text{Optimum stocking rate for the sward} < \text{Optimum stocking rate for the animal.}$$

The natural grazing lands of the world are very fragile ecosystems and population dynamics is an important aspect to be studied in grazing trials. Population is very sensitive to overgrazing, and in many situations only a relatively small proportion of the aerial biomass available can be recovered without irreparable damage to future production. This is in marked contrast to the proportion of the available forage which may be consumed in a strip grazing system on some cultivated pastures. Nearly all of the available forage may be recovered in such intensive systems (see figure 1).

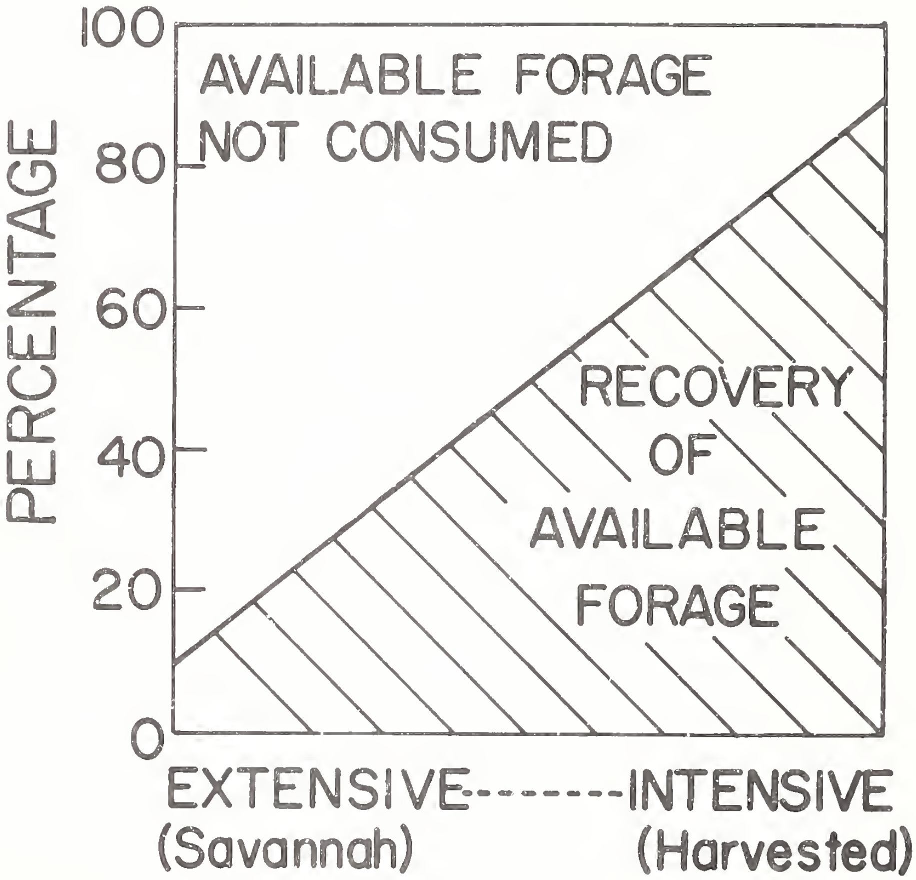

Figure 1. Proportion of Forage Recovered in Grazing Systems.

THE ANIMAL

Animal production and animal yield may have different definitions. Animal production is the amount of animal which is carried by the pasture. Animal yield, on the other hand, is that part of animal production which is harvested from the pasture. Live-weight gain, milk, and wool/ area are examples of animal yield.

There are many factors which influence the animal yield from pasture: (1) the environmental effects upon the pasture and the animal, (2) the botanical composition of the sward and the yield potential of the selected forages, (3) the cultural practices such as fertilization, irrigation, and pest control, (4) harvesting methods--mechanical or grazing, (5) types of animal, (6) forage quality, and (7) supplemental feeding, to mention only a few.

Animal yield/area is then a reflection of the amount of forage consumed per animal, its quality, and the amount of consumable forage available/area. The following relationship may be helpful in understanding the nature of animal yield/area:

(1) Yield/animal x Animals/area = Animal yield/area.
(2) Yield/animal = f (quality of consumed forage, animal potential, supplemental feed).
(3) Animals/area = f (amount of forage available, acceptability and consumption, and efficiency of conversion of consumed forage by the animal).
(4) Animal potential = f (age, size and sex, genetic potential, previous treatment, energetic efficiency, and environmental effects).

The above relationships suggest that if we can obtain reliable estimates of animal yield and the number of animals which an area will support, unencumbered by other variables, that animal yield/area can be computed with a minimum of bias.

ERRORS IN GRAZING TRIALS

Two kinds of error are of concern in grazing trials: random errors and bias errors. Random errors may be reduced to a minimum with the use of good experimental designs and use of statistical controls on concomitant variables. My remarks will be confined to sources of bias in grazing trials and how they effect the measurement of forage quantity and quality.

If stocking rate (animals/area or the reciprocal, area/animal) is to be a reliable estimate of the quantity of usable forage available--forage yield--then the pasture must be grazed at or near its optimum stocking rate. The estimation of the optimum stocking rate has been and is still a major problem in grazing trials. Since the pasture is in almost a continuous state of change it is easy to see why optimum stocking rate for the pasture may be quite different from the optimum for the animal. The optimum for the animal will be considered here since this is within the context of the topic of this paper. The short- and long-term effects on population dynamics and sward status will be ignored, although it is recognized that overgrazing and undergrazing may have a major influence upon the pasture. Lucas (1962b) states:

> Since man can control, either directly or indirectly, the status of the sward, sward status and its time course clearly should be considered one of the treatment variables. This is so regardless of whether the interest is in the factors affecting sward performances or in the animal's response to sward characteristics. Results should be interpreted, therefore, in terms of both sward status and other experimental variables.

It is important to distinguish whether the investigator is conducting a grazing trial to compare selected specific treatments where treatment x grazing pressure interactions could lead to erroneous conclusions, or whether one or more complete forage-livestock systems are being compared. The choice of fixed or variable stocking rates has been reviewed by Wheeler et al. (1973), and the beginner is strongly advised to read this publication very carefully as well as many of the references before initiating a grazing trial of any kind. It may save him from discarding several years of worthless data generated from

faulty techniques and the expenditure of considerable sums of money.

Many stocking rate studies have been conducted in the past 30 years, and there certainly is no unanimity of understanding with respect to what is meant by optimum stocking rate and how it may be attained (Riewe 1961, Jones and Sandland 1974)(fig. 2). It remains a tantalizing problem.

STOCKING RATE	0	1	2	3	4	5	6	7	8	9	10
Production /head	10	9	8	7	6	5	4	3	2	1	0
Production /area	0	9	16	21	24	25	24	21	16	9	0

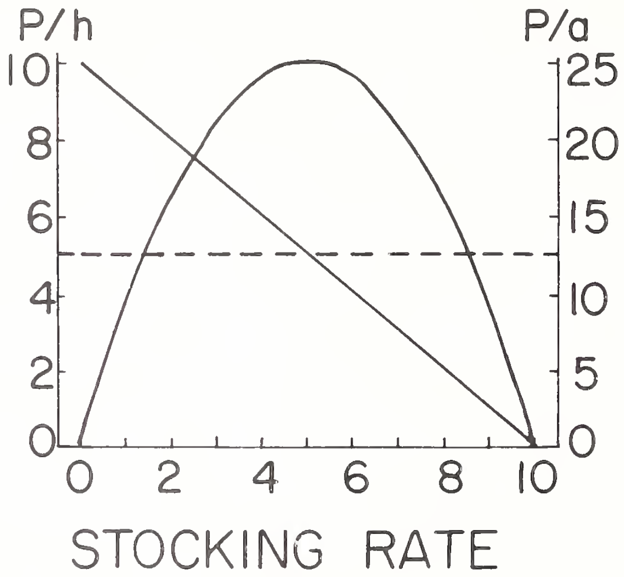

Figure 2. Gain/Animal and Gain/Area in Relation to Stocking Rate.

The theoretical relationship as proposed by Peterson et al. (1965) comes very close to describing the real situation. This is illustrated in figure 3. I would like to propose that there are now methods for estimating optimum stocking rates (optimum with respect to the animal) by completely objective procedures and that these methods may be sufficiently accurate for most purposes. These are based on an estimate of the utilizable available forage and upon the assumption that there is uniformity among most types of pastures with respect to the quantity of forage available per area and/or per animal per day at the optimum stocking rate. Willoughby (1958) stated that animal production (yield) eventually reached a maximum rate unaffected by further increases in pasture. Vohnout and Jimenez (1975) have expressed mathematically this relationship by the equation $Y = A+B \exp(-CX)$, where A = maximum weight gain, $A+B$ = weight loss if $X = 0$, and C = rate at which weight gain decreases as intake decreases. The question is, How much dry matter per hectare of acceptable forage needs to be

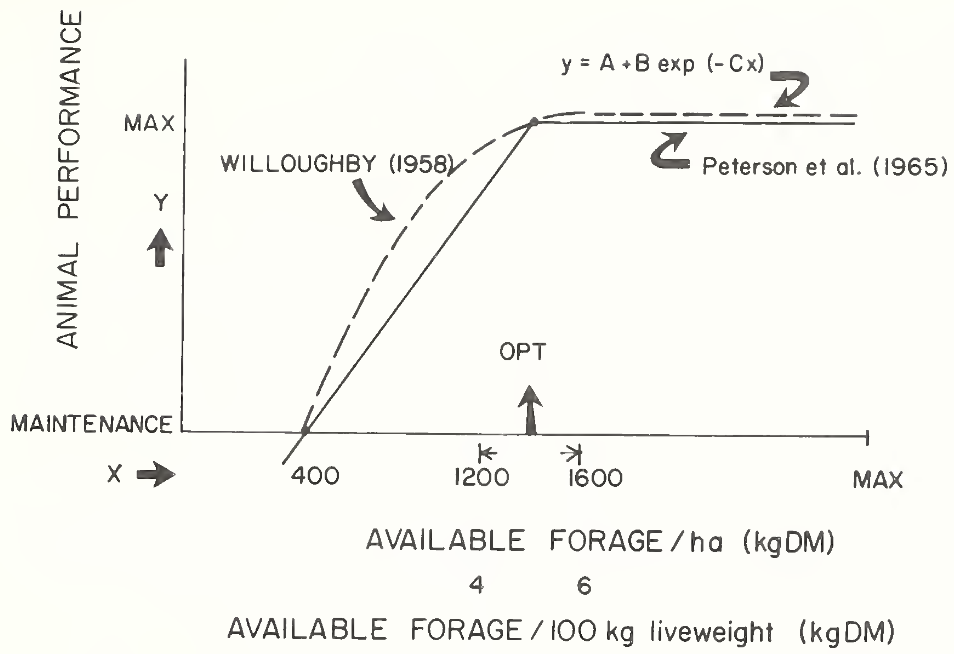

Figure 3. Relationship of Available Forage and Animal Performance.

available either on a per hectare or on a per animal per day basis so that the grazing animal may attain maximum consumption? Using the model proposed by Peterson et al. (1965) this point is probably reached at 1200 to 1600 kg/ha or from 4 to 6 kg per 100 kg liveweight/day. The latter range is about twice the consumption rate of the bovine on pasture. Estimation of the forage available either on a per area or per animal basis should enable the investigator to

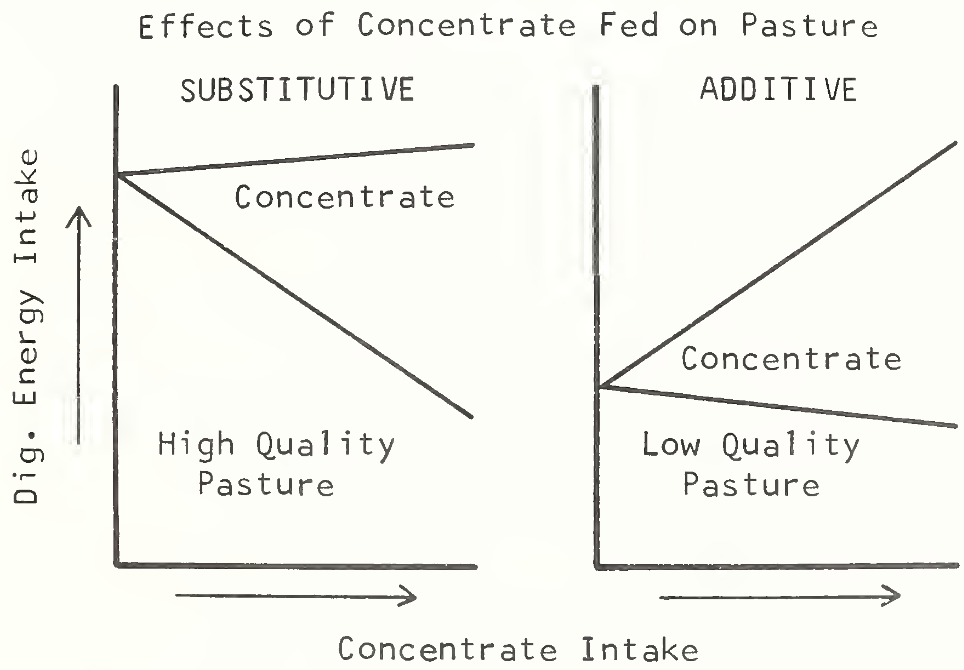

Figure 4. Schematic of the Substitutive and Additive Effects of Feeding Concentrates on Pasture.

use only one stocking rate, which can be estimated near the optimum for animal production. Providing forage at the *ad libitum* level, without an excess of feed, should provide for maximum animal yield consistent with the quality of that feed. It should be noted that the maximum animal yield may be quite different for pastures of different qualities.

Supplemental feeding on pasture has different effects depending upon the relative acceptability and consumption of the concentrate and pasture. Both additive and substitutive effects usually occur when any kind of supplemental feed or forage is fed, and unless proper designs and techniques are used, these effects may not be measurable (Mott et al. 1968). In general, the poorer the quality of the pasture the greater will be the additivity, and substitution will be minimal. If the quality is high, as with ryegrass-white clover or pearl millet pastures, the substitution may be high and the additivity minimal (Mott and Moore 1977) (fig. 4).

In most supplement-plus-pasture studies only the additive effects are measured and no consideration is given to a reduction in forage intake--the substitution effect. This leads to erroneous conclusions with respect to the efficiency of the supplement and its contribution to animal yield.

SUMMARY

The current pasture researchers owe a great debt to Dr. H. L. Lucas for his elucidations of the problems associated with the grazing trial. The animal is an excellent biological agent for assaying the quality and quantity of available forage providing proper techniques are used. Yield/animal gives reliable estimates of the quality of available forage, providing it is offered at an *ad libitum* level and animals/area measures the forage yield when the stocking rate is near the carrying capacity of the pasture. If overgrazing is permitted, then yield/animal will become a function of available forage rather than forage quality. If the pasture is either overgrazed or undergrazed then animal yield/area will be underestimated.

Supplemental feeds substitute for pasture at different rates depending upon the qualities of the supplement and the available pasture. The additive and substitutive effects of each combination of supplement and pasture must be determined quantitatively if economic analyses are to be made.

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DESIGNING RATIONAL EXPERIMENTS AT THE PLANT-ANIMAL INTERFACE: ADAPTED FROM DR. H. L. LUCAS, JR.

By Marvin E. Riewe

Perhaps no person has stimulated the thinking and research efforts of Southern U.S. scientists interested in the plant-animal interface as much as Dr. H. L. Lucas, Jr., did for the past thirty years. I first met Dr. Lucas, "Curly," as many of us knew him affectionately, in 1951. I was privileged to begin working with him in a more formal way in 1958 on Southern Regional Project S-45, "Nutritional Evaluation of Forage Crops." In Texas, we were fortunate to have Dr. Lucas work with us on our forage research program, as a consultant, for some five or six years. I personally valued his assistance with my own research interests. Because of this association with Dr. Lucas for over twenty years, I was privileged to have copies of several papers in my file, written by him, and insofar as I know, never published more formally. The text that follows here is taken almost verbatim from these papers.

QUANTITATIVE INFORMATION NEEDED

There is grave need to obtain quantitative information which will permit livestock producers to make intelligent management decisions as prices for land, cattle, supplementary feeds, soil amendments, labor, supplies, equipment, etc. shift. Such information should be of input-output form over wide ranges of input variables, such as stocking rates, pasture species, fertilizer levels, supplementary feeding, and various management alternatives such as pasture sequencing and creep feeding. Then, whenever the economic situation changes, the producer can adapt on sound grounds.

Although, in the long run, knowledge about how to maximize livestock production is important from the standpoint of society, maximization of production is not in general synonymous with maximization of profit (or minimization of loss) for the individual producer or for the industry. Depending on prices, submaximum production may often be an economic necessity. The research problem is to obtain information such that a producer can compute with some confidence what his input levels should be for any price situation. That is, information is needed so that operations can be "optimized."

Not only are the input variables numerous, but some of them interact strongly; the level of some variables can importantly condition the relation of output to other variables. A producer must consider jointly all factors and their interaction. To study experimentally all input variables in a joint way (e.g., by factorial experiments with each variable at several levels) is, of course, unfeasible. A researcher must, therefore, make judgments on what the most important input factors are, nutritionally and economically, and the ranges over which they should be studied. He must also make judgments about which interactions are important and which are not. He must then devise an experimental program which leads to quantitative statements (mathematical formu-

lae) about how output (animal production) is jointly related to the important input variables.

Unless a researcher has tremendous resources, it is impossible in a single grazing experiment to study more than one or two factors at a time and have each factor at several levels. Thus, a conceptual framework and an associated technique for integrating the results from different experiments are needed. The conceptual framework dictates in large part how individual experiments are to be designed and analyzed and the sequence in which experiments are to be conducted. An experimental program must be such that a producer can optimize significantly more precisely when experimental results become available than he was able to do before.

DESIGN AND ORGANIZATION OF RESEARCH EFFORTS

Aiming toward maximization of production instead of toward establishing input-output relations reflects a philosophy which has long permeated agricultural research. As a result, good data on input-output are extremely spotty; sound economic analyses are not generally possible. Producers have to adapt to price changes, however severe, as best they can, using the relatively few checkpoints agricultural research has provided but relying most heavily on their best judgment based on experience and intuition. (Dr. Lucas felt strongly that the philosophy for and goals of agricultural research generally had to be changed in the direction of establishing input-output relations. MER)

A framework for research programs designed to establish quantitative input-output relations at the plant-animal interface is shown schematically below.

Management Factors		Feed On Offer		Feed Consumed		Animal Production
Forage species Fertilizer levels Season of grazing Stocking rate Feed supplements* Etc.	→→→→	Nutritive character Amount per unit land	→→→→	Nutritive character Amount Per animal unit Per unit land	→→→→	Per animal unit Per unit land

*Including creep feeding (pasture or other).

The diagram points up what the research problems are. As already noted, it is impossible to set up giant factorial grazing trials in order to observe animal productivity directly for many combinations of levels of the management factors. Yet, one must come up with "formulae" whereby animal productivity can be well estimated for any set of management alternatives. This requires that the research be done in integratable pieces or phases, using methods less cumbersome and expensive than grazing trials wherever possible. The different phases of research may progress more or less simultaneously. Of course, grazing trials are essential for certain critical facets.

Integratable phases of research at the plant-animal interface are:

(A) Establishing relations of production per animal unit to amount and nutritive character of feed consumed per animal unit.
(B) Establishing relations of amount and nutritive character of feed consumed per animal unit to amount and nutritive character on feed on offer.
(C) Establishing relations of amount and nutritive character of feed on offer to levels of management factors considered jointly.
(D) Combining the relations established in (A), (B), and (C) into formulae which define the relations of production per animal unit and per acre to levels of the management factors.
(E) Validating and improving the formulae derived in (D).

Animal Nutrient Requirements (Phase A)

The only possible approach for Phase A is controlled (manger) feeding. There seems to be little reason, however, to do experiments for Phase A. Much is already known about how production per animal unit is related to amount and nutritive character of food consumed.

Selection by Animal of Feed Available (Phase B)

Information on how amount and nutritive character of feed consumed are related to amount and character of food on offer is scarce. This is a critical hiatus and is of special concern for grazing situations. Some things are known, of course. If a feed is offered in excess and is of such nature that animals <u>cannot</u> pick and choose the components eaten, then the amount consumed will increase up to a point as fibrousness decreases. Further, at a given level of fibrousness, consumption will decrease if the content of protein (and/or, e.g., some minerals) is below some point. If, however, a feed offered in excess is of such nature that animals <u>can</u> pick and choose, then, depending on the nutritive character of individual feed ingredients, consumption can be high even though the feed mixture would not be well consumed if the animals could not select. In grazing situations, unless the forage available per unit time is too small, animals can pick and choose. For scanty pastures, selectivity depends on forage density (amount per unit of area) and on search rate of animals. For nonscanty pastures, selectivity depends on the amount of forage to which animals have access in a unit of time, and that in turn depends jointly on forage density and the area of access allowed per unit of time.

Manger feeding trials

"Manger" feeding trials can be used extensively in Phase B to learn how amount and nutritive character of forage consumed are related to nutritive character of forage offered. In such studies, fresh-cut forages of widely varying nutritive character (as described by chemical measures and "in vitro" digestibilities) would be the treatments. There are numerous possibilities, but the actual number of different types of harvestings can be greatly restricted. The goal is to obtain feeding materials of widely different nutritive character. One can use any way of obtaining the cut forages that yields the desired spectrum of characteristics.

In these studies, the forages should usually be offered in excess. In addition to recording amount and nutritive character of forage offered, one would have to measure amount and character of refusals so that amount and character of what was consumed could be computed. Provision should also be made for animals to pick and choose what they consume. This implies "cafeteria-type" feeding facilities wherein animals are offered choice among one or more forages and supplements.

Such experiments inherently involve many treatments; all treatments need not, however, be compared at the same time. By invoking the incomplete-block concept of experimental design, one can, through a series of trials, study many treatments, and over a sufficient period of time, the necessary information for relating amount and character of feed consumed to amount and character of feed offered can be obtained.

Feeding periods (length of time a given treatment is applied to an animal) can be short (two or three weeks at most) because no attempt need be made to assess animal rates of gain. One is simply aiming to establish relations of forage consumed to forage offered as conditioned by characteristics of the animal.

To assess the relations, data are analyzed basically by regression methods, not by analysis of variance procedures.

The important matter is to use many treatments in order to realize wide variations in characteristics of feeds offered, mode of offering, and animal characteristics, with each treatment variable fairly orthogonal to every other one.

Grazing trials

For Phase B, grazing trials must be invoked to learn some things that cannot be assessed from "manger" trials. Mainly, one has to learn how forage density affects the amount which can be consumed and how density interacts with forage character and supplemental feeding. As stocking rate is increased above some critical level, selectivity and amount consumed become progressively restricted by the rate at which animals can search for feed. Because the goal of grazing trials for Phase B is to ascertain how consumption is related to the density and the character of the pasturage as conditioned by supplemental feeding, the treatment variables should be:

(i) Forage density varied over a wide range.
(ii) Nutritive character of forage available varied over a wide range.
(iii) Supplemental feeding.

The design should be some sort of factorial-like pattern; say, four levels of forage density, three or four different nutritive quantities at each density and two or three levels of supplementary feeding. In addition to measuring performance of "tester" animals, it is critical to estimate frequently, by clipping or otherwise, and by chemical and "in vitro" methods, the amount and the character of the forage available, and <u>also, the amount and the character of forage consumed</u>.

Again, essentially regression methods would be used for analyzing data. It is important to employ as large a number of treatments as can be managed, with minimal replication (say, two paddocks per treatment with three tester animals per paddock).

Effect of Management Factors on Feed Available (Phase C)

The only feasible way to obtain most of the information for Phase C is by agronomic means. Basically, one would set up small-plot factorial-like studies in which the treatment variables are:

(i) The revelant forage species (and perhaps mixtures).
(ii) Fertilizer rates and types (if thought important).
(iii) A variety of mechanical harvesting (clipping) regimens.

The clipping regimen should be selected so as to simulate widely varying stocking rates and grazing at different times of year and should include a "mocking" of late summer and fall "stockpiling" for winter grazing. This requires clipping procedures different from the standard agronomic ones.

To accomplish the simulation of continuous, slow-rotational, or seasonal grazing requires treatments something like:

(i) Allowing the forage to grow to different heights or ages before clipping is started in order to simulate varying conditions under which animals are put to pasture.
(ii) Once clipping is started, to clip every few days (at longest each week), removing the "top" portion of the sward in varying amounts over a broad enough range to ensure that possible animal consumption rates at various stocking rates are encompassed.
(iii) A few days (a week) before top clipping is started on a plot, a subplot of that plot should be cut to "ground level," and each time "top" clipping is done on that plot, another subplot should be clipped to "ground level."

The purpose of (i) and (ii) is rather obvious. The productivity of a pasture per unit area depends on the amount of manufacturing (photosynthetic) material present (forage density); hence, one must measure both amount "topped off" and amount remaining (iii).

The goal basically is to ascertain how the time change in sward productivity and, hence, in amount and nutritive character of forage available are related to forage density and rate of removal as conditioned by forage species, season, etc. That information is critical. Amount and character of forage available at a point in time determine amount and character of forage removed by grazing animals during the immediately succeeding time interval. That, in turn, regulates density and character of forage available at the next point in time, which in turn regulates removal during the following time interval etc. One needs, therefore, to conduct the agronomic trials of Phase C in such a way that the relations obtained can be combined with the relations of forage consumption (removal) per animal unit to forage offered (available) established in Phase B (and stocking rate). By so combining, one can build up, by using a sequence of short time intervals, what the time course of forage availability and consumption per animal unit and per unit of land will be under grazing.

Grazing trials at different stocking rates and appropriate seasons on representative species are needed to calibrate the agronomic results; i.e., to see how agronomic results need to be adjusted to correspond to grazing at different stocking rates in different time patterns. Reasons are: clipping every few days instead of daily or oftener (like animals graze), trampling

effects, excretal return, and "spotty" grazing. It seems that, with some ingenuity, the grazing trials and measurements outlined for Phase B could be augmented and/or modified somewhat to serve also for the calibration aspects of Phase C.

(Both practical and theoretical problems are immediately encountered when one truly wishes to simulate grazing; nevertheless, the lack of a reasonable estimate of forage growth under grazing is a serious deficiency. MER)

Translation of Biological Concepts into Mathematical Statements (Phase D)

Phase D is purely logical in nature. That is, it involves concepts and translation of the concepts into mathematical statements and associated algorithms (computational or arithmetic formulae). For this, mathematical relations developed in Phases A, B, and C must be "tied" together.

The role of mathematical models

Some hold the view that experimental results cannot be very useful unless study is made of a "total system" and its output under various inputs (e.g., full-scale grazing trials). Others argue that such "extensive" approaches are too cumbersome and expensive to be used as the mainstay of forage and pasture research. It is stressed, correctly, that only a few of the infinite number of input and environmental situations to be met in practical operations can possibly be studied by extensive means, i.e., the information realizable about input-output relations usable in an objective way is extremely limited. The alternative proposed is to separate forage and pasture systems into their basic components (e.g., soil, forage components, animal components) and to make "intensive" study of the behavior of the individual components. Those who favor the extensive approach then ask, however, "How, since the components of a forage and pasture system interact so strongly, can knowledge of the behavior of the individual components be integrated to provide proper input-output relations for the total system?"

A partial answer is, "By study, not just of the components themselves, but also of the mechanisms whereby the components are coupled with each other; e.g., the interfacing of sward and animal in grazing system." This answer is not satisfying to many people, however, because they do not conceive of a method for integrating the knowledge about the behavior and the interfacing or coupling of individual components into a total-system input-output relation. Hence, to augment the answer, it must be pointed out that mathematical concepts and methods can be employed, and, in fact, that <u>mathematical approaches are the only means whereby the integration can be accomplished</u>.

The answer still is not complete, however, unless one stresses a further fact. The results of intensive experimentation and associated mathematical modeling efforts will be of limited value unless done in a way that takes proper cognizance of the basic nature of forage and pasture systems; i.e., of the inherent structural and behavorial characteristics.

Dynamic nature of forage-animal systems

If there is a single factor which leads some people instinctively to feel that extensive approaches give the only realistic answers, it is that most intensive research in the past has not properly taken into account the

dynamic nature of forage-animal systems. Further, until recently modeling efforts for forage-animal systems have not explicitly incorporated dynamic features. Since extensive experimentation can be used only sparingly, and further progress must rest predominately on intensive experimentation and associated modeling, it is cogent to discuss the dynamic aspect and to examine its implications.

The amount and character of each and all components of a forage and pasture system, the intensity and mode of their interaction, and their performance or productivity continually shift through time. In a grazed pasture, for example, there is continuing change in sward and animals and continuing mutual feedback between sward and animals. Amount and character of forage being removed by animals at a given time depend on amount and character of forage available, character of animals, and stocking rate at that time; and performance (e.g., weight gain) of animals at that time is conditioned by amount and character of forage being consumed. Removal of forage, however, affects productivity of the sward, causing changes in amount and character of forage available at a later time; also, forage consumed affects character of the animals at the later time. These factors in turn cause, at the later time, changes in amount of character of forage being removed by animals and performance of the animals, with subsequent further changes in sward productivity, amount and character of sward, and character of animals. An additional dynamic aspect is introduced if man varies stocking rate from time to time.

The essential dynamic nature of the system is not changed under mechanical harvesting of forage as contrasted to grazing or under different modes of grazing; only the pattern of interfacing or coupling between forage and animal is modified. Thus, properly developed mathematical models for sward response to defoliation and for animal response to forage on offer will apply for any way of manipulating forage-animal systems; different models are not needed for different situations.

The foregoing analysis of the dynamics implies a certain kind of conceptual framework as necessary to guide intensive experimentation and mathematical modeling efforts.

Mathematical framework

Fortunately, there already exists a mathematical medium for describing the behavior of dynamic systems. It is the logical structure and the methodology known to mathematicians as the field of differential and difference equations.

Systems of differential or difference equations are statements of the time changes and the output rates of the components of a physical (biological) system at a given point in time. The time change of a given component and the rates of different outputs are written as functions of the state of the several components of the system at the given time, and of the rates of different inputs to the given component; the inputs to any component can be from any or all other components within the system or from outside the system.

Given a system of differential or difference equations that adequately describes the behavior of the system of interest (here a forage-animal system), given the state of the system at a point in time in terms of the state of each facet, and given the time courses of conditioning factors and rates of input from outside the system, the state and the output rates of the system at any subsequent point in time can be found by the process known to mathematicians as "integration."

To accomplish the integration in nonvague terms requires specification of the functional forms for the time changes in state and the output and input rates for each facet of the system. In simple systems it is often possible to accomplish the integration formally (i.e., employing symbolic representations for variables, parameters, and logical operations) to yield a directly useful result. In complicated system, however, arithmetic approaches (numerical integration) must be invoked. This requires not only the functional forms but also numerical values for the initial state of the system and any parameters and constants involved in the functions; it also requires that the time courses of extrasystematic inputs and conditioning factors be translated to numerical terms.

High-speed computing has rendered feasible the numerical integration required for quantifying complicated dynamic phenomena, and there is rapidly increasing use of systems of differential or difference equations as models of real-world systems (among the biological fields, it is pronounced in ecology) and thence their integration by computer. This approach is being used increasingly to gain insight about the response of real-world systems to various input patterns and to aid in making management and policy decisions.

In current parlance, the process of writing models and performing the numerical integration, or at least the integration step, is commonly called "system simulation" or, simply, "simulation."

"Tying Together" Phases A, B, and C (Phase D)

Now, we return to "tying together" the mathematical relations developed in Phases A, B, and C. The outline will correspond to difference equations. For simplicity, neglect factors such as season, fertilizer levels, genetic makeup of animal units and forage species; those are not critical to the general conceptual framework and can be introduced as needed with minor difficulty. Adopt a short time interval (the shorter the better); to be concrete, however, let the time interval be a week. Let <u>performance</u> stand for weight change of animal. Let <u>state of animal</u> stand for weight of animal. Let <u>forage consumption</u> stand for forage consumption of animal. Let <u>forage available</u> stand for both density (amount per unit of land) and quality of forage available. Let <u>supplement</u> stand for feed supplement provided animal.

Phase B yields:

Forage consumption per animal during first week = function of forage available at beginning of first week, supplement per animal during first week, and state of animal at beginning of first week.

Forage consumption (forage removed) per unit of land during first week = forage consumption per animal during first week times animals per unit of land during first week.

Phase C yields:

Forage available at beginning of second week = function of forage available at beginning of first week, forage consumed per unit of land during first week, forage growth during first week, and loss of forage from system during first week.

Phase A yields:

Performance per animal during first week = function of amount and nutritive character of forage consumed per animal during first week, supplement per animal during first week, and state of animal at beginning of first week.

State (weight) of animal at beginning of second week = state of animal at beginning of first week plus change in state (performance) of animal during the first week.

Performance per unit of land during first week = performance per animal during first week times animals per unit land during first week.

Having completed the computations just indicated for the first week, one replaces "first week" by "second week" and "second week" by "third week" in all the statements and accomplishes the computations for the second week, then third week, etc., week after week. This process (numerical integration is accomplished with high-speed computers.

Given the relations (functions) established in Phases A, B, and C, then, one can examine the input-output picture for myriads of different of management alternatives and compare the profitabilities of different alternatives for many price situations. At the start of any week, one can simulate changing the nature of animal units (e.g., removing calves), shifting from one kind of pasture to another, changing stocking rate, changing the supplemental feeding, and/or changing the price structure.

Validating and Improving Models (Phase E)

Using the relations developed in Phases A, B, and C and integrating them (Phase D) as just outlined, one estimates ("predicts") productivity (per unit of land and per animal unit) for a wide variety of management alternatives. These alternatives should involve a variety of forage species, widely varying stocking rates, a number of different species sequencings through the year, different methods of supplementary feeding of cows and calves, etc. From among these alternatives, one then selects a limited number which vary widely with respect to inputs (levels of the management variables) and "predicted" productivities. These selected alternatives are then employed as the treatments in actual grazing experiments to "test" and to obtain clues for improvement of the prediction formulae.

One need not wait until Phases A, B, C, and D are completed to begin Phase E. Some of the management alternatives to examine can be visualized at the outset; hence, some trials to provide data for Phase E can be started anytime.

Symposium
Forage Evaluation in the 80's: The Legacy of Dr. H. L. "Curly" Lucas

RELATIONSHIPS BETWEEN THE PROPERTIES OF SOUTHERN FORAGES AND ANIMAL RESPONSE

Preliminary Report on Regional Project S-45

By J. E. Moore, J. C. Burns, A. C. Linnerud, and R. J. Monroe

INTRODUCTION

Forages produced in the southern region include legumes and grasses of four types: temperate perennial, temperate annual, tropical perennial, and tropical annual. Because of the diversity of animal performance on southern forages, Regional Project S-45 was initiated in 1970 to pursue the following objectives with a selected group of southern forages:

1) Characterize their chemical properties and *in vitro* dry matter disappearance.
2) Determine the following animal responses: (a) voluntary intake, (b) nutrient digestion and absorption, (c) energy utilization and (d) rate of gain.
3) Evaluate their forage characteristics and associated animal responses as predictors of animal productivity.

This report consists of a brief summary of experimental procedures and major results. A Southern Regional Cooperative Series Bulletin is planned and will include details of procedures and complete results.

EXPERIMENTAL PROCEDURES

Contributions to the project were made by 10 state experiment stations, Puerto Rico, and USDA laboratories at Athens, Ga., and Beltsville, Md. (Table 1). Hays were produced and fed at eight locations. There were a total of 66 cuttings representing 10 cultivars, four types (alfalfa, temperate perennial grasses, tropical annual grasses, and tropical perennial grasses) and, in some cases, two locations (Table 2). In most cases, harvests were made at three stages of maturity.

Animal response objectives of the project were met with the exception of nutrient (amino acid) absorption and energy utilization (animal calorimetry). Animal responses included average daily gain (43 hays), voluntary intake (54 hays) and nutrient digestibility (62 hays) (Table 2). Gain and intake data were obtained with six cattle (per hay) and digestibility with sheep or cattle (six per hay). Nine 'Haygrazer' hays (three locations and three maturities) were to be involved in a reciprocal exchange among Louisiana, Oklahoma, and Texas. Hays made at one location were to be fed to two animals at each of the three locations. However, data on only six of the hays were analyzed statistically because all exchanges were either not made or all hays not fed.

Table 1. State Contributions to Southern Regional Research Project S-45

State	Type of Contribution	Specific Contribution
Alabama	Laboratory	Nylon bag, *in vitro*
Florida	Hay production	3 bahiagrass and 3 digitgrass
	Animal responses	Intake, gain and digestion
	Laboratory	*In vitro*, detergent fractions, minerals, silica
Georgia	Laboratory	*In vitro*
Kentucky	Hay production	8 tall fescue and 4 orchardgrass
	Animal responses	Intake, gain and digestion
	Laboratory	Proximate analysis, amino acids
Louisiana	Hay production	12 bermudagrass, 3 bahiagrass and 3 sorghum x sudan
	Animal responses	Intake, gain and digestion
	Laboratory	*In vitro*, detergent fractions, proximate analysis, minerals
Mississippi	Hay production	3 sorghum x sudan
	Animal responses	Digestion
	Laboratory	Nylon bag, *in vitro*, detergent fractions
North Carolina	Laboratory	*In vitro*, detergent fractions
Oklahoma	Hay production	4 sorghum x sudan
	Animal responses	Intake, gain and digestion
Puerto Rico	Laboratory	Detergent fractions, proximate analysis, minerals
Tennessee	Hay production	3 orchardgrass and 3 tall fescue
	Animal responses	Intake, gain and digestion
	Laboratory	*In vitro*, detergent fractions, proximate analysis
Texas	Hay production	3 sorghum x sudan and 3 bermudagrass
	Animal responses	Intake, gain and digestion
USDA-Athens	Laboratory	Fatty acids
USDA-Beltsville	Hay production	8 orchardgrass and 3 alfalfa
	Animal responses	Intake and digestion
	Laboratory	*In vitro*, detergent fractions, silica, total N

Table 2. Summary of Hays Produced and Those Included in Various Statistical Analyses

Cultivar	State[a]	Number of cuttings	Number of Hays Analyzed Gain	Intake	Digestion	Lab
Alfalfa, Williamsburg	UB	3	--	3	3	3
Fescue, Kenwell	KY	4	1[b]	1[b]	4	4
Fescue, Kentucky 31	KY	4	1	1	4	4
Fescue, Kentucky 31	TN	3	3	3	3	3
Orchardgrass, Boone	KY	4	1	1	3	4
Orchardgrass, Boone	TN	3	3	3	3	3
Orchardgrass, Potomac	UB	8	--	8	8	8
Sorghum-Sudan, Haygrazer	LA	3	3	3	3	5[c]
Sorghum-Sudan, Haygrazer	OK	4	4	4	1	2[d]
Sorghum-Sudan, Haygrazer	TX	3	3	3	3	6[e]
Sorghum-Sudan, SX-16	MS	3	--	--	3	3
Bahiagrass, Pensacola	FL	3	3	3	3	3
Bahiagrass, Pensacola	LA	3	3	3	3	3
Bermudagrass, Coastal	LA	12	12	12	12[f]	12
Bermudagrass, Coastal	TX	3	3	3	3	3
Digitgrass, Pangola	FL	3	3	3	3	3
Total		66	43	54	62	69

[a]State code is the Post Office abbreviation, except UB = USDA, Beltsville.

[b]Omitted from Analysis of Variance.

[c]Includes samples of two hays fed in Texas as well as Louisiana.

[d]Samples of one hay fed in Louisiana and Texas.

[e]Includes samples of three hays fed in Louisiana as well as Texas.

[f]Nine hays omitted from correlation analyses involving digestibility.

Laboratory analyses included a broad spectrum of procedures (Table 1). Details of methodology will be included in the Regional Bulletin. A list of abbreviations is provided in Table 3.

Statistical analyses utilized the SAS program packages for least-squares analysis of variance, and correlation analysis. Data on certain samples had to be deleted from various analyses for a variety of reasons but the data set for a given analysis was judged to be optimum for that analysis (Table 2). This report includes data and statistics on only a small portion of the total data set. Additional chemical analyses as well as many computed parameters of intake and digestibility will appear in the Bulletin.

RESULTS

Animal Responses

There were wide variations among hays in average daily gain (Table 4), and there were both maturity and cultivar effects ($P<.01$). Animals fed fescue, orchardgrass, and digitgrass had higher gains than those fed sorghum-sudan, bahiagrass, and bermudagrass. The high gain recorded for digitgrass is surprising because of the low intake of that grass (Table 4). Boone orchardgrass had high quality as shown by both gain and intake data.

Voluntary intake of DM and digestible DM (Table 4) were affected ($P<.01$) by maturity and cultivars, and they followed similar trends among cultivars. Intakes of alfalfa, Boone orchardgrass, and bermudagrass were highest, while intakes of digitgrass, bahiagrass, and sorghum-sudan were lowest. There were no consistent trends due to type of forage.

Calculated intake of NDF was affected by maturity ($P<.05$) and cultivar ($P<.01$), but the intake of ADF was affected ($P<.05$) by cultivar only. Among intake parameters, ADF intake was the least variable across hays. Trends among grass cultivars were similar for intakes of DM, DDM, NDF, and ADF. Alfalfa had the lowest intake of NDF but the highest of DM, DDM, and ADF, no doubt reflecting the low NDF content of alfalfa.

Calculated values for excretion of DM, NDF, and ADF (Table 4) showed no effect of maturity, but cultivars differed ($P<.01$). Excretion of ADF was most variable, in contrast to the low variability in ADF intake. Alfalfa had the highest values for excretions, fescue the lowest, and other forages were generally similar. Excretions of DM and NDF were correlated ($r=.83$, $n=39$; $P<.01$) as were excretions of DM and ADF ($r=.76$, $n=39$; $P<.01$).

There were wide variations in nutrient digestibility (Table 5), decreasing with increasing maturity ($P<.01$) and among cultivars ($P<.01$). Types were also different ($P\leq.05$). The type effect was associated with the low digestibility (less than 50%) of NDF and ADF in alfalfa. Digestible NDF and ADF (Table 5, as percent of DM) were not affected by maturity. Alfalfa had the lowest values, due to both low content and digestibility of NDF and ADF. Digestible energy and DM digestibility were positively correlated ($r=.93$; $n=40$; $P<.01$).

Undigestible NDF and ADF increased with maturity ($P<.01$) in contrast to digestible NDF and ADF which were not affected by maturity (Table 5). Lowest values of undigestible NDF and ADF were in 'Kentucky 31' fescue and 'Potomac' orchardgrass, whereas highest values were in digitgrass (NDF) and alfalfa (NDF and ADF). There were no consistent trends among the three types of grasses in digestibilities, digestible nutrients, or undigestible nutrients.

Table 3. List of Abbreviations[a]

ADF =	acid detergent fiber
ADL =	acid detergent lignin
BAR =	Barnes *in vitro* digestion
Ca =	calcium
CF =	crude fiber
CP =	crude protein
D prefix =	digestible
D suffix =	digestibility (%)
DM =	dry matter
EE =	ether extract
GVS =	Goering and Van Soest *in vitro* digestion
I suffix =	intake (g/kg MW)
K =	potassium
LOF =	local in vitro digestion, 48 hours
Mg =	magnesium
MW =	metabolic weight (body weight $^{.75}$)
NBF =	nylon bag digestion, 48 hours
NDF =	neutral detergent fiber
NRG =	energy (Mcal/kg dry matter)
OM =	organic matter
PML =	permanganate lignin
TFA =	total fatty acids
TT =	Tilley and Terry *in vitro* digestion
U prefix =	undigestible

[a]Values without suffix are expressed as percent of dry matter (unless otherwise indicated).

Table 4. Maturity and Cultivar Means of Daily Gain, Daily Intake and Daily Fecal Excretion[a]

Item	Item Code	Daily Gain n	Daily Gain kg	Daily Intake, $g/kg^{.75}$ n	DM	DDM	NDF	ADF	Daily Excretion, $g/kg^{.75}$ n	DM	NDF	ADF
Range: High	HI	--	.888	--	116.0	81.8	84.8	47.2	--	50.2	34.8	24.7
Low	LO	--	-.270	--	55.1	28.1	38.1	23.6	--	27.0	15.5	10.2
Coefficient of Variation (%)	CV	--	85.2	--	17.0	23.7	17.6	13.7	--	12.3	17.4	21.2
Analysis of Variance[b]	AOV	42	HMC	53	MC	MC	mC	c	49	C	C	HCt
Maturity: A	MA	14	.518	17	99.4	61.6[c]	65.9	36.4	16	38.3	23.2	14.9
B	MB	14	.356	18	92.2	53.9[c]	62.9	36.6	17	38.5	25.3	16.1
C	MC	14	.169	18	83.5	45.4[d]	59.9	35.6	16	37.8	25.7[c]	16.6[c]
Cultivar:												
Alfalfa, Williamsburg	AW	--	--	3	107.3	62.2	53.3	41.4	3	45.1	30.0	23.3
Fescue, Kenwell	FK	--	--	--	--	--	--	--	--	--	--	--
Fescue, Kentucky 31	FY	4	.452	4	88.6	57.8	64.5	36.6	4	30.8	18.3[c]	11.9[c]
Orchardgrass, Boone	OB	4	.595	4	104.5	61.2[c]	72.2	40.1	3	39.7	25.7	16.0
Orchardgrass, Potomac	OP	--	--	8	92.8	57.5	60.9	34.5	8	35.3	19.9	13.1
Sorghum-Sudan, Haygrazer	SH	10	.169	10	82.6	48.1[e]	57.6	35.5	7	38.9	25.3	17.4
Sorghum-Sudan, SX-16	SX	--	--	--	--	--	--	--	--	--	--	--
Bahiagrass, Pensacola	BA	6	.184	6	80.3	44.4	59.3	30.7	6	35.9	23.5	13.1
Bermudagrass, Coastal	BC	15	.176	15	97.9	58.0	75.5	36.1	15	39.8	26.9	15.1
Digitgrass, Pangola	PA	3	.511	3	79.5	39.7	60.1	35.2	3	39.8	28.3	17.1

[a]Refer to Table 3 for explanation of abbreviations

[b]Capital letter = $P<.01$, lower case letters = $P<.05$; H,h, = hays; M,m, = maturity; C,c,= cultivar; T,t = type (alfalfa vs. temperate perennial vs. tropical annual vs. tropical perennial); refer to appropriate column for variations in n.

[c]One sample missing

[d]Two samples missing

[e]Three samples missing

Table 5. Maturity and Cultivar Means of Digestibibility, Digestible Nutrient, and Undigestible Fiber[a]

Item Code[b]	Digestibility, %					Digestible Nutrient, DM basis					Undigestible Fiber, % of DM		
						Fiber %			Energy/kg				
	n	DM	NDF	ADF	CP	n	DNDF	DADF	n	Mcal	n	UNDF	UADF
HI	--	70.5	77.6	71.9	74.5	--	58.6	33.0	--	3.05	--	41.7	25.1
LO	--	44.4	40.1	41.1	32.9	--	15.7	13.0	--	1.86	--	13.4	8.7
CV	--	9.6	12.4	11.4	15.2	--	17.4	12.4	--	12.5	--	20.1	22.5
AOV[c]	62	hMC	HMct	HMct	HMC	60	HCt	C	39	MC	48	MC	MC
MA	20	62.2	65.2	60.5	64.9	20	42.9	21.5	12	2.66	16	23.6	15.1
MB	21	59.1	60.8	57.1	59.4	21	40.6	22.1	13	2.43	17	27.9	17.6
MC	21	54.9	57.0[e]	53.8[e]	52.6	19	41.4	22.9	14	2.32	15	32.1	20.6
AW	3	57.8	43.6	43.5	70.4	3	21.5	17.1	3	2.68	3	28.0	21.8
FK	4	63.4	64.9[d]	61.1[d]	59.6	3	39.1	19.7	4	2.68	--	--	--
FY	7	63.9	67.9[d]	64.0[d]	59.2	6	45.9	25.2	7	2.74	3	22.6	14.7
OB	6	61.2	66.4	61.3	62.7	6	43.6	22.5	6	2.61	3	26.0	16.2
OP	8	60.7	66.2	61.2	62.6	8	42.8	23.2	--	--	8	22.3	14.7
SH	7	55.0	59.2	53.5	60.0	7	42.2	23.3	7	2.29	7	29.5	20.3
SX	3	62.3	65.3	60.4	55.3	3	43.6	22.5	3	2.75	--	--	--
BA	6	54.6	59.9	57.1	47.2	6	45.6	22.7	3	2.26	6	29.8	16.8
BC	15	58.8	63.9	58.1	64.2	15	51.8	22.6	3	2.16	15	28.5	16.0
PA	3	49.6	52.4	51.0	48.3	3	40.6	23.3	3	2.09	3	36.0	21.7

[a] Refer to Table 3 for explanation of abbreviations.

[b] Refer to Table 4 for definition of Item Codes

[c] Refer to Table 4, footnote b for explanation of Analysis of Variance codes.

[d] One sample missing

[e] Two samples missing

Average daily gain was correlated with intake and digestibility parameters (Table 6). Intake of DM was correlated with DM digestibility (r=.69), and digestible DM intake was nearly as highly correlated with DM digestibility (r=.88) as with DM intake (r=.95). Intake of DM was not correlated (P>.05) with digestibilities of NDF and ADF. Undigestible NDF (as percent of DM) was well correlated with digestible DM intake (r=-.83) and undigestible ADF with digestible NDF intake (r=-.81).

The digestibility of dry matter (Table 7) was highly correlated with digestibilities of organic matter (r=.99) and energy (r=.97). Digestibilities of NDF and ADF were highly correlated (r=.96). Digestibilities of CF and OM were each highly correlated with other fractions, but the number of observations was low (n=9 to 28). Correlations between DM digestibility and the digestibilities of NDF or ADF were not high (r=.73 and .77, respectively).

The data on animal responses and the correlation analyses suggest that, with the occasional exception of alfalfa, there were no major discrepancies among the various types of forages with respect to forage quality. This was further supported by application of the Lucas test of nutritional uniformity to neutral detergent solubles (NDS) and to crude protein (CP), giving the following equations:

$$\text{Apparent digestible NDS} = 1.03 \pm .04\ (\text{NDS}) - 16.4 \pm 1.4\ (r=.958;\ n=51)$$

$$\text{Apparent digestible CP} = 0.81 \pm 0.04\ (\text{CP}) - 2.58 \pm 0.46\ (r=.949;\ n=53)$$

These data confirm that NDS and CP are nutritive entities, that is, they have uniform true digestibilities across all forages. Furthermore, the data show that NDS has a true digestibility equal to 100% and a metabolic fecal excretion of 16.4% of DM intake; this latter value is higher than the 12.9% reported by Van Soest. The true digestibility of CP in these forages was estimated to be 81%, which is lower than the approximately 88 to 94% reported elsewhere. Metabolic CP excretion of 2.58% was close to the expected value. These data suggest that further attention be given to southern forages with respect to:

1) A possibly higher than expected metabolic fecal excretion of NDS, thus decreasing available energy content below the potential, and
2) A possibly lower than expected true digestibility of CP which, since NDS has 100% true digestibility, suggests that in some hays an appreciable amount of forage nitrogen may be associated with indigestible cell walls, or otherwise does not behave as a part of cell contents.

Laboratory Characteristics

Maturity and cultivars affected all chemical components determined (Table 8), and there were differences due to type in NDF, ADL, Ca, and P. The former three were associated with alfalfa. Tropical grasses were lowest in P. Alfalfa had lowest NDF and the tropical perennial grasses the highest NDF. The most variable chemical components were Ca and TFA, followed by CP, EE, and ADL. The highest TFA and EE values were found in orchardgrass.

In vitro and nylon bag digestions were affected by maturity, cultivars, and type (Table 9). Generally, tropical perennial grasses had lower values,

Table 6. Correlations[a] Among Average Daily Gain, Voluntary Intake, Digestibility, and Undigestible Fiber[b]

Item		Ave. Daily Gain	Voluntary Intake DMI	DDMI	NDFI	DNDFI
Voluntary Intake:						
	DMI	.55(43)	--	.95(41)	.77(54)	.52(39)
	DDMI	.73(30)	.95(41)	--	.62(41)	.61(39)
	NDFI	.37(43)	.77(54)	.62(41)	--	.86(39)
	DNDFI	.67(28)	.52(39)	.61(39)	.86(39)	--
Digestibility:						
	DMD	.63(30)	.69(41)	.88(41)	.46(41)	.66(39)
	NDFD	.55(28)	.22(39)[c]	.43(39)	.52(39)	.87(39)
	ADFD	.53(28)	.24(39)[c]	.46(39)	.50(39)	.84(39)
Undigestible Fiber:						
	UNDF	--	-.64(39)	-.83(39)	-.41(39)	-.70(39)
	UADF	--	-.48(39)	-.67(39)	-.52(39)	-.81(39)

[a]Correlation coefficients (r) followed by number of observations in parentheses; all values are significant (P<.05) unless indicated otherwise.

[b]Refer to Table 3 for explanation of abbreviations.

[c]P>.05

Table 7. Correlations[a] Among Nutrient Digestibilities[b]

Item	DMD	NDFD	ADFD	OMD	NRGD	CFD	CPD
DMD	--	.73(51)	.77(51)	.99(28)	.97(40)	.86(12)	.63(53)
NDFD	.73(51)	--	.96(51)	.90(28)	.60(38)	.94(12)	.33(51)
ADFD	.77(51)	.96(51)	--	.89(28)	.63(38)	.87(12)	.28(51)
OMD	.99(28)	.90(28)	.89(28)	--	.99(28)	.84(9)	.73(28)
NRGD	.97(40)	.60(38)	.63(38)	.99(28)	--	.87(12)	.66(40)
CFD	.86(12)	.94(12)	.88(12)	.85(9)	.87(12)	--	.63(12)
CPD	.63(53)	.33(51)	.28(51)	.73(28)	.66(40)	.63(12)	--

[a]Correlation coefficients (r) followed by number of observations in parentheses; all values are significant ($P<.05$).

[b]Refer to Table 3 for explanation of abbreviations.

Table 8. Maturity and Cultivar Means of Chemical Composition

Item Code[a]	Chemical Composition, % (DM basis)[b]											Total fatty acids	
	n	CP	CF	NDF	ADF	ADL	Ca	Mg	P	K	EE	n	%
HI	--	20.2	39.6	81.8	47.9	8.68	1.43	.55	.86	3.85	4.29	--	0.96
LO	--	5.5	24.5	45.1	30.1	2.52	.22	.12	.22	.59	1.26	--	0.09
CV	--	30.4	11.2	11.2	11.6	25.8	56.7	39.4	23.2	35.1	30.1	--	55.8
AOV[cd]	69	HMC	HMC	HMCT	HMC	HMct	HMct	HmC[e]	HMCT[f]	HMC[g]	HMC	36	MC
MA	22	14.9	30.3	64.7	35.5	4.55	.58	.24	.69	2.25	2.99	11	.49
MB	23	11.3	32.1	66.3	38.2	4.92	.51	.23	.64	2.26	2.76	12	.34
MC	24	9.5	35.7	70.9	42.1	5.86	.49	.19	.54	1.74	2.28	13	.23
AW	3	17.7	33.1	49.2	38.6	7.93	1.39	.21	.73	2.16	2.80	--	--
FK	4	11.9	28.8	60.8	33.3	3.36	.59	.24	.76	1.53	3.43	--	--
FY	7	10.5	33.2	67.1	37.9	3.82	.39	.20	.69	2.18	2.51	4	.32
OB	7	12.5	33.4	67.2	37.7	4.71	.43	.19	.73	2.44	3.58	4	.58
OP	8	15.3	32.4	65.5	37.4	4.59	.39	.19	.72	3.26	3.32	6	.54
SH	13	9.7	35.3	71.5	42.9	5.39	.32	.41	.48	1.73	2.28	10	.24
SX	3	11.8	30.2	66.1	37.6	3.98	.62	.19	.55	2.56	2.89	3	.33
BA	6	9.8	31.2	73.7	38.7	5.42	.30	.27	.57	1.83	1.78	3	.35
BC	15	12.1	32.5	77.0	37.8	5.43	.32	.16	.54	1.89	2.14	3	.23
PA	3	7.9	36.7	75.1	44.1	6.46	.47	.16	.47	1.25	2.06	3	.23

[a]Refer to Table 4 for definition of item codes

[b]Refer to Table 3 for explanation of abbreviations

[c]Refer to Table 4, footnote b for explanation of Analysis of Variance codes.

[d]Differences among laboratories occurred with all determinations (P<.01) except total fatty acids (one laboratory only).

[e]Maturity by cultivar interaction (P<.05)

[g]Hay by laboratory interaction (P<.01)

[f]Maturity by type interaction (P<.05)

Table 9. Maturity and Cultivar Means of *In Vitro* and Nylon Bag Digestion

Item Code [a]	n	Percent Digested [b]				
		TT	BAR	GVS	LOF	NBF
HI	--	77.0	77.6	89.0	74.9	89.4
LO	--	37.5	37.9	51.6	34.9	29.6
CV	--	13.4	14.3	10.8	17.8	15.8
AOV [c]	69	HMCT	HMCT	HMCT	HMCT	HMCT
MA	22	63.6	65.4 [d]	78.4	64.4	70.2
MB	23	59.8	60.4	72.9	60.0	64.9
MC	24	53.9	54.3	67.3	53.5	57.2
AW	3	60.9	62.4	73.2	60.9	73.3
FK	4	63.7	64.7	76.9	64.8	67.4
FY	7	62.3	64.7	77.8	64.7	63.8
OB	7	64.9	65.5	78.8	64.7	66.9
OP	8	65.3	66.6	78.1	65.2	73.5
SH	13	57.5	58.6 [d]	71.0	58.3	62.9
SX	3	64.1	65.2	77.4	65.9	63.9
BA	6	50.6	50.5	67.6	49.7	60.4
BC	15	51.4	51.1	65.9	48.9	53.5
PA	3	50.3	50.9	61.9	49.6	55.2

[a] Refer to Table 4 for definition of Item Codes.

[b] Refer to Table 3 for explanation of abbreviations.

[c] Refer to Table 4, footnote b for explanation of Analysis of Variance.

[d] One sample missing.

which is not completely consistent with the *in vivo* data (Table 5). The *in vitro* data are discussed by Nelson in more detail elsewhere in this volume.

All laboratory analyses (Table 10) showed differences ($P<.01$) among laboratories, and *in vitro* and nylon bag digestions showed hay by laboratory interactions ($P<.01$). The mean values suggest that there was as much, if not more, variation among laboratories in chemical analyses as there was in *in vitro* digestions. However, it should be noted that different numbers of hays were analyzed by different laboratories.

Prediction of Animal Responses

Although the number of samples were low (24 to 32), the most consistent single predictor of gain, intake and digestibility was TFA (Table 11). The validity to such a relationship is suggested by the correlations between EE and DM intake ($r=.59$), digestible DM intake ($r=.72$), and DM digestibility ($r=.72$), with from 41 to 51 samples. There were also high correlations between P and digestible DM intake ($r=.74$) and DM digestibility ($r=.75$). In addition, average daily gain was correlated with Ca ($r=.62$) and P ($r=.59$). Further research is required to determine if these correlations represent cause-effect relationships.

Among fractions given by various fiber and lignin analyses, NDF was most closely correlated with average daily gain ($r=.59$); ADF with DM intake ($r=-.65$), digestible DM intake ($r=-.71$), and DM digestibility ($r=-.73$); and ADL with NDF digestibility ($r=-.79$). Digestibilities of DM and NDF were not as highly correlated with PML as with ADL. No single predictor was closely correlated with NDF intake.

The relatively high correlation between ADF and DM intake (Table 11) is consistent with the low variability associated with ADF intake (Table 4). The suggestion that ADF is a major determinant of forage DM intake is in contradiction to the widely accepted hypothesis that intake is controlled by NDF.

Reciprocal Exchange of Hays

Except for PML ($P<.05$), there were no differences in chemical composition or *in vitro* digestion among hay samples received from two states where the forages were fed (Table 12). Therefore, the forages fed in each state were of similar composition and potential digestibility. However, animal responses differed among states where the forages were fed (Table 13). These differences were not consistent among states; for example, the states having the intermediate average daily gain had the highest intakes of DM and digestible DM. Differences in digestibilities among states were significant, though small. Intake differences may have been related to differences in hay preparation methods among states.

Those data suggest that the correlations between forage characteristics and animal responses among all forages may have been influenced by real differences among states in the animal responses; that is, forage and state effects may have been confounded. The high gain but low intake of the steers fed digitgrass is a case in point. It is surprising, in light of this, that the correlations obtained in this study are as high as they are. It is tempting to assume that if state differences in the animal responses could be removed, that the correlation values would be improved; such an assumption may be completely erroneous, however.

Table 10. Laboratory Means of Chemical Composition, and in Vitro and Nylon Bag Digestion[a]

Lab[b]	CP	CF	EE	NFE	NDF	ADF	TT	BAR	GVS	LOF	NBF
AL	--	--	--	--	--	--	58.9[c] (44)	--	--	--	59.6 (57)
FL	--	--	--	--	68.5 (60)	39.5 (60)	--	--	--	56.5 (60)	--
GA	--	--	--	--	--	--	--	--	--	58.5 (35)	--
KY	10.6 (58)	31.4 (50)	2.57 (59)	--	--	--	--	--	--	--	--
LA	12.8 (68)	31.7 (68)	3.37 (68)	45.2 (68)	71.3 (68)	40.2 (68)	--	60.1 (68)	70.9 (68)	--	--
MS	--	--	--	--	68.1 (64)	38.8 (64)	58.6 (64)	--	--	--	68.6 (61)
NC	--	--	--	--	65.6 (64)	37.6 (64)	--	59.9 (64)	--	56.6 (64)	--
PR	12.4 (52)	35.8 (52)	2.88 (52)	41.7 (44)	68.5 (60)	38.5 (60)	--	--	--	--	--
TN	12.2 (60)	31.9 (57)	1.89 (57)	47.3 (57)	--	--	59.9 (60)	--	--	--	--
UB	12.4 (57)	--	--	--	65.6 (57)	38.0 (57)	--	--	74.8 (42)	--	--
AOV[d]	L	L	L	L	L	L	L HXL	-- HXL	L HXL	L HXL	L HXL

[a]Refer to Table 3 for explanation of abbreviations

[b]Lab codes are Post Office codes, except UB = USDA, Beltsville

[c]All means are as percent, with the number of hays analyzed shown in parenthesis below the mean.

[d]Analysis of Variance: L = laboratories differed ($P<.01$), HXL = hay by laboratories interaction ($P<.01$).

Table 11. Correlations[a] Between Animal Responses and Overall Mean Chemical Composition[b]

Item	Ave. Daily Gain	Voluntary Intake			Digestibility	
		DMI	DDMI	NDFI	DMD	NDFD
CP	.37(40)	.54(54)	.63(41)	.19(51)[c]	.53(53)	.30(51)
CF	-.19(40)[c]	-.42(51)	-.52(41)	-.25(51)[c]	-.58(53)	-.46(51)
EE	.50(40)	.59(51)	.72(41)	.26(51)[c]	.72(53)	.47(51)
TFA	.65(24)	.70(30)	.77(29)	.41(30)	.69(32)	.67(30)
NDF	-.59(40)	-.41(51)	-.68(41)	.29(51)	-.61(53)	-.03(51)[c]
ADF	-.30(40)[c]	-.65(51)	-.71(41)	-.44(51)	-.73(53)	-.52(51)
ADL	-.53(40)	-.35(51)	-.51(41)	-.43(51)	-.71(53)	-.79(51)
PML	-.54(37)	-.26(48)[c]	-.39(38)	-.35(48)	-.58(50)	-.69(48)
Ca	.62(40)	.30(51)	.36(41)	-.29(51)	.18(53)[c]	-.40(51)
P	.59(40)	.30(51)	.74(41)	-.11(51)[c]	.75(53)	.46(51)
K	.47(37)	.11(48)[c]	.52(38)	-.18(48)[c]	.50(50)	.42(48)
Mg	.08(40)[c]	-.05(51)[c]	.06(41)[c]	-.17(51)[c]	.01(53)[c]	-.01(51)[c]

[a]Correlation coefficients (r) followed by number of observations in parentheses; all values are significant ($P<.05$) unless indicated otherwise.

[b]Refer to Table 3 for explanation of abbreviations.

[c]$P>.05$

Table 12. Composition and In Vitro Digestion of Haygrazer Hays in the Reciprocal Exchange Among States

Stage of Maturity	State Where Grown[b]	State Where Fed[b]	Composition, %			In Vitro Digestion, %		
			CP	NDF	PML	TT	GVS	IOF
A	LA	LA	11.5	73.9	5.39	62.3	75.1	62.1
		TX	12.6	71.7	5.05	60.1	73.9	63.1
A	TX	LA	11.4	70.4	5.79	59.2	74.7	61.8
		TX	16.4	64.6	4.55	62.2	79.6	66.3
B	OK	LA	5.8	64.9	7.35	57.5	69.9	58.4
		TX	5.8	65.2	6.66	55.4	70.1	58.6
B	TX	LA	9.6	72.5	6.85	57.8	71.5	58.5
		TX	9.1	69.5	5.75	57.9	74.1	61.1
C	LA	LA	9.6	75.2	7.65	53.5	69.9	53.9
		TX	8.6	74.9	7.18	52.4	63.6	54.2
C	TX	LA	7.2	76.2	8.05	47.5	64.8	47.7
		TX	7.1	75.5	7.45	48.1	66.0	50.8
Analysis of Variance[c]			HG	HG	HMGf	Hmg	HmG	HMG

[a]Refer to Table 3 for explanation of abbreviations.

[b]State codes are Post Office abbreviations.

[c]Capital letters = P<.01, lower case letters = P<.05; H, h = hays, M, m = maturity, G, g = state where grown, F, f = state where fed.

Table 13. Daily Gain, Voluntary Intake and Digestibility of Hays in the Reciprocal Exchange Among States[a]

Stage of Maturity	State Where Grown[b]	State Where Fed[b]	Daily Gain (kg)	Voluntary Intake, g/MW DM	Voluntary Intake, g/MW DDM	Digestibility, % DM	Digestibility, % NDF
A	LA	LA	.402	122.1	71.7	58.7	63.9
		OK	.480	78.7	43.4	55.1	60.0
		TX	.294	74.9	44.1	58.8	66.3
A	TX	LA	.330	115.9	71.2	61.4	68.6
		OK	.693	93.3	53.7	57.6	61.7
		TX	.568	93.9	54.6	58.1	62.6
B	OK	LA	.143	107.9	62.3	57.7	55.2
		OK	.188	70.4	37.7	53.5	48.2
		TX	-.239	64.1	34.4	53.7	53.6
B	TX	LA	.536	107.3	59.5	55.5	61.4
		OK	.436	86.9	50.5	58.1	61.3
		TX	.162	72.3	39.8	55.1	59.9
C	LA	LA	.232	116.7	63.6	54.5	59.9
		OK	.213	73.4	37.5	51.0	51.7
		TX	-.157	63.2	30.9	48.9	56.9
C	TX	LA	.089	107.6	55.8	51.9	57.7
		OK	.178	75.7	33.9	44.8	49.2
		TX	-.134	60.8	30.7	50.5	58.6
Mean	Mean	LA	.289	112.9	64.0	56.6	61.1
		OK	.365	79.8	42.8	53.4	55.3
		TX	.082	71.6	39.1	54.2	59.6
Analysis of Variance[c]			GF	gF	GF	mGf	GF

[a]Refer to Table 3 for explanation of abbreviations.

[b]State codes are Post Office abbreviations.

[c]Capital letters = P <.01, lower case letters = P <.05; M, m = maturity, G, g state where grown, F, f = state where fed.

SUMMARY AND CONCLUSIONS

Objectives of Southern Regional Project S-45 were to examine (1) quality-related characteristics of forages in the Southeastern U.S. and (2) inter-laboratory variations in *in vivo* and laboratory data. Hays were produced and fed to cattle and/or sheep in eight states, and analyses were conducted in 11 laboratories. There were 66 hays representing 10 cultivars, four types (alfalfa, temperate perennial grasses, tropical annual grasses and tropical perennial grasses), three stages of maturity, and, in some cases, two locations. Six of the hays were exchanged among three states for *in vivo* comparisons.

Average daily gain (ADG) was measured on 42 hays, and they ranged from -.27 to .89 kg. Voluntary intake was measured on 53 hays, and dry matter (DM) intake ranged from 55 to 116 g/MW. Digestion trials were conducted on 62 hays, and DM digestibility ranged from 44% to 71%. There were main effect differences ($P<.01$) due to maturities and cultivars in ADG, intake of DM and digestible DM, and digestibilities of DM, neutral detergent fiber (NDF), and acid detergent fiber (ADF). Across all hays, ADF intake was the least variable intake measurement; only cultivars differed ($P<.05$). In the exchange study, there were differences ($P<.01$) among states in ADG, DM intake, and NDF digestibility.

Intake of DM was correlated with DM digestibility ($r=.69$, $P<.05$). Digestible DM intake was correlated ($r=-.83$) with undigestible NDF (as % of DM, based on *in vivo* digestibility). Digestibility of DM was correlated with digestibility of NDF ($r=.73$) and of ADF ($r=.77$).

There were main effect differences ($P<.01$) due to maturities, cultivars and laboratories in chemical composition and *in vitro* digestion and *in vitro* digestion showed hay by laboratory interactions ($P<.01$). Using across-laboratory means, NDF was correlated with ADG ($r=-.59$), DM intake ($r=-.41$), and DM digestibility ($r=-.61$). However, ADF was more highly correlated than NDF with DM intake ($r=-.65$) and DM digestibility (-.73). Correlations (r) between *in vivo* and *in vitro* digestion ranged from .68 to .93 among laboratories.

Improvement of animal performance on southern forages will depend upon overcoming limitations of cell wall utilization. Broad application of prediction models will require more attention to interlaboratory variations.

Symposium
Forage Evaluation in the 80's: The Legacy of Dr. H. L. "Curly" Lucas

SOURCES OF VARIATION IN THE IN VITRO DIGESTION OF SOUTHERN FORAGES

By Billy D. Nelson

Forage quality may be defined as those factors affecting animal response and is controlled by voluntary intake and digestibility. However, these factors are far too complex to expect a single laboratory analytical or biological technique to relate to all of them in a significant way. For many years the conventional intake and in vivo digestion trial was the only method available to obtain reliable forage quality values. This technique is very time consuming and laborious, thereby limiting the number of forages from which data may be obtained.

In efforts to circumvent the disadvantages of in vivo digestion trials and to facilitate and expedite forage quality work, many researchers began investigating techniques simulating the microbial activities of the rumen. These works led to the development of several in vitro fermentation systems Johnson (1966). In the fifties and early sixties a number of researchers began developing their own fermentation procedure. Donefer et al. (1960) studied the relationship between 12-hour in vitro cellulose digestibility and Nutritive Value Index, an expression of digestibility and intake. Baumgardt and et al. (1962) reported a within-trial variation range of 0.32 to 0.79 and a between-trial variation of 1.02 for in vitro cellulose digestion of an alfalfa meal substrate studied through 13 trials. Tilley and Terry (1963) carried the rumen simulation one step farther and added a proteolytic digestion to insure similarity to that process in the lower gut. With this two-stage procedure, they reported a standard error of estimate of 2.31 for prediction of in vivo digestible-dry-matter of 146 forages.

Barnes (1965) emphasized that a useful laboratory method for the routine evaluation of forages must not only be relatively simple but also must produce results with a high degree of precision and repeatability, and give an accurate, unbiased, estimate of forage quality. The precision of in vitro systems is associated with the magnitude of the variability within and between trials

The Tilley and Terry (1963) two-stage rumen fermentation procedure as modified by Barnes (1969) and Goering and Van Soest (1970) is generally recognized as the most reliable in vitro procedure for the estimation of digestibilities in vivo. Work by Oh et al. (1966) demonstrated the reliability of the two-stage in vitro technique. In the development of these in vitro procedures and modifications, only temperate grass and legume species were used as shown below.

Investigator	No. Forages Used in Study	
	Legume	Temperate
Oh et al. (1966)	21	35
Barnes (1965)	3	9
Goering & Van Soest (1970)	12	8

Four major factors affecting the variability in the in vitro digestion of not only southern forages but all forages are forage species, sample preparation, inoculum microbial population, and laboratory techniques and procedures.

FORAGE SPECIES

Akins et al. (1973) found that leaf tissue of tall fescue was degraded more rapidly and extensively in vitro than that of Coastal bermudagrass. McLeod and Minson (1969) reported that satisfactory results with tropical grasses were achieved only after the in vitro method, Tilley and Terry (1963), had been controlled to a far higher standard than appears necessary for temperate grasses. Working with four tropical pasture species and one temperate grass, they found a maximum predicted difference of 3.5 digestibility units. Burdick et al. (1979), when using the near-infrared filter spectrometer, found that tropical and temperate forage species required different wavelengths to predict forage quality parameters.

The 1979 progress report of the AFGC Hay Marketing Task Force, using acid-detergent fiber and crude protein as the laboratory variables for 54 legumes, reported a highly significant correlation (r=0.79) between predicted DDM and in vivo DDM. A correlation of 0.75 was shown between predicted DDM and in vivo DDM for 230 grasses. When NDF percentage was used as a laboratory variable, a correlation of 0.64 was found between predicted and actual intake of legumes. A correlation of 0.78 was shown between predicted and actual intake of the 230 primarily temperate grass species. Moore (1980) reported a nonsignificant correlation (r=0.17) between predicted and actual intake from data accumulated from 63 forages, including southern perennial and annual species, in the S-45 work project when using the same regression equations reported in the AFGC Hay Task Force progress report. A correlation of 0.66 was found between predicted in vivo DDM of these same 63 forages with the AFGC regression equations. These data demonstrate different behavioral patterns between laboratory and animal response values of southern forages than are found in temperate grass and legume species.

Grant et al. (1974), using 22 tropical forages, found that true dry matter digestibility in vitro of tropical grasses increased for each 24-hour increase in fermentation of 48, 72, and 96 hours.

Digestibility	Fermentation Period		
	48-h	72-h	96-h
Dry matter	73.4^a	75.6^b	77.3^c
Cell wall	61.5^a	64.8^b	67.4^c

Nelson et al. (1969) have shown a high correlation (r=0.92) between in vivo and in vitro digestion values of 13 temperate grass species compared to a correlation of 0.72 for 13 southern perennial grasses. The 26 forages were incubated in the same water bath at the same time with the same source of rumen fluid. Forage type was the only variable in this investigation.

Data clearly show different results are obtained with different forage species. They also suggest that, since the in vitro procedures and modifications were developed utilizing primarily temperate grass species, new modifications of in vitro techniques may be needed to adequately estimate quality of southern forages.

SAMPLE PREPARATION

Sample Drying and Storage. The adage that analytical data cannot be any better than the sample is certainly true in determining in vitro digestion values. A representative sample of the forage to be tested must be obtained. Van Soest (1965) has shown the damage that occurs when drying forage at a high temperature. A nonenzymatic browning reaction occurs when forage is dried at temperatures above 50°C. This browning reaction can affect in vitro digestion values. Sugars in the forage disappear when heat exceeds 45-50°C, and some nitrogen becomes unavailable by forming artifact lignin. If these nutrients are in low supply in the substrate to be digested, the cellulytic bacterial action will be limited.

The apparent sugar content of hay declines with age. Clark and Mott (1960) emphasized the influence of storage upon the in vitro/in vivo relationship.

Particle Size. McLeod and Minson (1969) studied the effects of particle size on the variability of in vitro fermentation systems, using three sizes of screens, 0.4, 1.0, and 1.96 mm, in grinding the samples. They found the in vitro digestion values increased with each reduction of particle size with four grass species. The magnitude of the difference varied between species, but increasing the fermentation time reduced the magnitude of difference. They stated very satisfactory results could be obtained using samples ground through a 1-mm screen.

Sample Size. Tilley and Terry (1963) recommended the use of 0.5-gram samples when incubating with 10 ml of rumen fluid and 40 ml of McDougall's buffer. McLeod and Minson (1969) studied the effects of sample size, using 14 forage samples, ranging in in vivo digestibility from 41.2% to 66.7%. In vitro digestibility was measured in duplicate, using six sample sizes: 0.5, 0.6, 0.7, 0.8,

0.9, and 1.0 gram. The in vitro digestion values decreased steadily as the sample size increased, but there was no interaction between the magnitude of the decrease in digestibility with increasing sample size. They concluded that no useful improvement in the accuracy of the in vitro technique could be expected by increasing the sample size from the recommended 0.5 gram.

Grant et al. (1972) studied sample size when investigating type of fermentation vessels for an in vitro fermentation procedure. The sample size was 250, 375, and 500 mg. Even though they found significant differences in digestion values among the sample size, these differences were very small.

Fermentation vessel	Sample Size 250	375	500	Mean
	- - - - - - - - - mg	- - - - - - - - -		
Erlenmeyer flask	74.5	74.9	75.6	75.0
Centrifuge tube	72.6	73.0	72.3	72.6
Screwcap vials	75.2	74.7	73.3	74.4
Mean	74.1	74.2	73.8	

INOCULUM MICROBIAL POPULATION

Possibly the largest source of error or variability in the in vitro system may be caused by the inoculum microbial population. Factors that may contribute to variability are animal difference, diet of donor animal, and processing of inoculum.

Animal Differences. Bezeau (1965) found a highly significant difference in the activity of the inocula from two donor animals fed the same diet, a conclusion which was contrary to results reported by Donefer et al. (1960).

Nelson et al. (1972) found highly significant differences in the in vitro digestible dry matter values of hays using inocula from three different donor animals. No differences were found in the IVDDM values of the alfalfa and bermudagrass substrates, but significantly different IVDDM values with high standard deviations were found for bahiagrass and ryegrass substrates among donor animals.

Comparison of IVDDM of four hays using inoculum from three donor animals without nutrient additives

Inoculum source	Alfalfa	Bahiagrass	Bermudagrass	Ryegrass
Jersey	76.52^{a}	68.33^{a}	69.51^{a}	67.53^{a}
SD	2.42	4.03	3.06	3.72
Holstein 1	76.78^{a}	68.75^{a}	70.46^{a}	65.31^{b}
SD	1.92	3.29	6.33	5.16

(Comparison of IVDDM of four hays using inoculum from three donor animals without nutrient additives--Continued)

Inoculum source	Alfalfa	Bahiagrass	Bermudagrass	Ryegrass
Holstein 2	76.02[a]	64.17[b]	70.37[a]	65.12[b]
SD	1.20	7.73	3.05	5.28

With the addition of urea and glucose to the fermentation media, no significant difference was found in the IVDDM values of the substrates among donor animals.

Comparison of IVDDM of four hays using inoculum from three donor animals with nutrient additives

Inoculum source	Alfalfa	Bahiagrass	Bermudagrass	Ryegrass
Jersey	76.43[a]	70.69[a]	70.87[a]	68.88[a]
SD	3.04	2.45	3.75	2.69
Holstein 1	76.88[a]	69.57[a]	72.21[a]	68.77[a]
SD	1.58	3.95	5.30	3.45
Holstein 2	76.35[a]	69.77[a]	71.09[a]	68.91[a]
SD	1.67	2.83	4.53	3.70

Barnes (1969) conducted a collaborative study with the two-stage in vitro technique modification of Tilley and Terry (1963). Three samples within each of four forage species, alfalfa, canarygrass, bromegrass, and fescue exhibiting a wide range of in vivo DDM values, were obtained, and 13 laboratories used these forages for in vitro digestion trials. Each laboratory used exactly the same procedure outlined by Barnes.

Nine of the laboratories had significant or highly significant differences among runs. Seven of the laboratories had highly significant run X forage interactions, indicating differences in digestibility of various forages were not of the same order of magnitude from run to run. Source of inoculum was the major difference among laboratories. These data suggest differences in inocula from donor animals and also differences of inoculum from the same donor animal from day to day. Barnes stated the use of inoculum dry matter disappearance as an index of reliability with each in vitro run appears feasible. Results of the study indicates that in vitro runs with less than 60% inoculum dry matter disappearance should be reviewed critically for possible interaction between run and treatment.

Diet of Animal. Alfalfa hay, because of its usually high crude protein and soluble carbohydrate content, is generally accepted as the most desirable diet of donor animals. An adequate supply of nutrients is available for the rumen microflora.

Nelson et al. (1972) have shown inocula used for in vitro digestion trials from donor animals fed alfalfa diets result in

less variability among trials and among donor animals.

Effect of diet of donor animal on the IVDDM of four hays

Diet	Substrate			
	Alfalfa	Bahiagrass	Bermudagrass	Ryegrass
Alfalfa	78.40[a]	67.21[b]	71.41[ab]	66.37[b]
SD	1.48	2.81	3.08	2.84
Bahiagrass	78.55[a]	61.96[c]	66.31[c]	60.21[c]
SD	3.63	10.46	5.50	6.05
Bermudagrass	76.65[b]	72.12[a]	73.54[a]	69.22[a]
SD	2.05	2.69	2.17	3.62
Ryegrass	75.63[b]	68.58[b]	71.37[ab]	68.16[ab]
SD	1.19	1.85	2.05	2.67

[a]Means in same column with different superscripts differed significantly P<01.

Processing of Inoculum. The first consideration of inoculum Processing must be with the aspects of time of feeding the donor animal in respect to time of removal of rumen fluid. Barnes (1969) adequately describes a successful method. The donor animal should be removed from all feed and water at least 2 hours before the rumen fluid is to be extracted. This prevents a dilution of the fluid with water and prevents the difficulty of rumen fluid removal from a tightly packed rumen mass.

It is much more desirable to extract the fluid with a vacuum system than by hand squeezing the fluid from the rumen content. By attaching a suction strainer to a rod and using vacuum, the fluid can easily be removed from the lower dorsal area more quickly. It is important to receive the fluid from the donor animal in a thermal flash preheated to 40°C.

Speed is of utmost importance at this stage of the fermentation procedure. In our laboratory, the substrate is weighed into the fermentation vessel along with the buffer solution and placed in the waterbath preheated to 39°C. By utilizing this procedure, we are able to complete the start of our in vitro digestion and have anaerobic conditions in the fermentation tube within 15 minutes after the extraction of rumen fluid.

LABORATORY TECHNIQUES AND PROCEDURES

Other than rumen fluid inoculum, laboratory techniques and procedure may result in the largest variation of in vitro digestibility. Barnes (1965) has stated that the errors associated with in vitro procedures can be considered in two categories. The factors which contribute to the lack of precision of results, "random errors," and the failure of the in vitro results to estimate the digestibility of the forage, "bias errors."

The magnitude of errors reflecting the precision of in vitro methods are those primarily associated with with-in trial variabil-

ity. The failure of the investigator to handle each sample exactly the same contributes to the random variation.

Although the correlation coefficient may be high, the prediction equation derived from in vivo/in vitro relationships may have limited value if the errors are large. Standard errors of estimate of digestibility have ranged from 2.0 to 4.4 for the prediction of in vivo digestion from in vivo results,Barnes (1965). Barnes stated that, to be of practical use, a regression equation should be capable of predicting digestibility within a standard error of not greater than 2 digestion units.

Nelson et al. (1972) found the variability between in vitro run and between donor animal could be reduced significantly with the addition of glucose and urea to the fermentation media. The standard deviations of bahiagrass, bermudagrass, and ryegrass were reduced significantly and IVDDM values were increased; however, the nutrient additive did not affect results from an alfalfa substrate.

Effect of glucose and urea additive on the fermentation media of an in vitro system

	Alfalfa	Bahiagrass	Bermudagrass	Ryegrass
Without additive				
means	76.53	67.53	70.59	66.27
SD	2.02	5.88	3.91	4.74
With additive				
means	76.77	70.67	72.51	69.47
SD	1.97	2.02	2.35	2.40

The effects of six fermentation times, 24 through 84 hours at 12-hour intervals, were studied on in vivo/in vitro relationships, repeatability, and variability of the Goering and Van Soest in vitro technique by Nelson et al. (1976). Southern perennials, summer annuals, temperate grass species, and alfalfa were used in the study.

For one fermentation time for all types of forages, a 48-hour fermentation demonstrated the smallest variation among runs and the least run X forage interaction. However, the optimum fermentation time for perennials as a group was 60 hours; and for legumes, annuals, and temperate grasses, 36 hours.

Further studies in vitro compared a 48-hour fermentation for all types of forages with 36 hours for annuals and 60 hours for perennials. Forty-eight forages, including 20 annuals and 28 perennials, were included in this study.

Statistical comparison of fermentation times

Source	DF	Variance components % 48-h	Variance components % 36 & 60-h
Forage	47	86.43	98.53
Run	2	6.88	0.33
Forage X Run	94	6.44	0.90
Error	144	0.25	0.24
Cv		0.74	0.58
Sy. x		2.40	2.49

Data from in vitro and nylon bag digestion studies accomplished in the S-45 work project are shown below. Eight laboratories utilized one or more in vitro techniques described by Tilley and Terry (1963), Barnes (1969), Goering and Van Soest (1970), and/or their local modifications. Fifty-three forages, including 15 southern perennials, 25 temperate grasses, 3 alfalfa, and 6 summer annuals, were included in this study. The in vivo DDM values ranged from 44.4% to 70.4%. A highly significant different interaction of procedure x state was found for all in vitro techniques except for the Barnes (1969) and local 72-hour procedures. A highly significant hay x state interaction was found for all procedures.

Regression analyses of in vitro procedures and laboratories with in vivo DDM

	Tilley and Terry L1	Tilley and Terry L2	Tilley and Terry L3
r	0.87	0.90	0.57
Sy.x	4.35	3.37	6.59
Cv	7.60	5.65	11.03
obsv.	48	53	43

	Goering-Van Soest L4	Goering-Van Soest L5
r	0.93	0.91
Sy.x	3.03	3.39
Cv	4.16	4.78
obsv.	36	53

Regression analyses of in vitro procedures and laboratories with in vivo DDM

	Barnes L6	Barnes L5
r	0.86	0.89
Sy.x	4.71	3.74
Cv	7.92	6.22
obsv.	49	53

	48-h local L6	48-h local L7	48-h local L8
r	0.87	0.83	0.87
Sy.x	4.86	5.07	3.96
Cv	8.64	9.03	6.91
obsv.	49	53	35

(Regression analyses of in vitro procedures and laboratories with in vivo DDM--Continued)

	72-h local			Nylon bag 48-h		72-h
	L7	L8		L1	L3	L1
r	0.85	0.87	r	0.78	0.37	0.85
Sy.x	4.54	3.45	Sy.x	6.04	10.19	4.72
Cv	7.22	5.47	Cv	9.00	17.60	6.52
obsv.	53	35	obsv.	45	50	45

Most of the correlation coefficients are considered adequate to good. Some of the standard error of predictions are quite large and the predicted digestion values have only limited value. However, other standard error of prediction values are well within the range of acceptable values, especially considering the wide type and range of quality of forage used in this study.

Data from laboratories utilizing the same in vitro procedure were pooled and results are presented below. Results from laboratory 3, utilizing the Tilley and Terry (1963) procedure, were omitted because of the lower than normal correlation and the high coefficient of variation.

Comparison of several in vitro procedures

	TT	GVS	Bar	L48-h	L72-h
obsv.	101	89	102	137	88
r	0.87	0.88	0.87	0.85	0.85
Sy.x	4.00	3.84	4.23	4.72	4.18
Cv	6.82	5.36	7.07	8.36	6.64

The Goering-Van Soest (1970) procedure exhibited a slightly higher correlation and lower standard error of prediction and Cv value. However, these data show only small differences in the reliability of the five in vitro procedures studied in this investigation.

In conclusion, I refer to a statement attributed to Dr. Barnes. He stated a successful in vitro system must produce results with a high degree of precision and repeatability and give an accurate unbiased estimate of forage quality. It also must be simple. By utilizing known factors that affect variability of in vitro systems now in use, and by modifying these procedures to more precisely estimate southern tropical forages, the in vitro systems can be a valuable tool in southern forage quality work. However, I doubt if it will ever be considered a simple procedure.

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RESEARCH AND EXTENSION PROGRAMS IN TENNESSEE FOR CLOVER ESTABLISHMENT IN TALL FESCUE SODS

By Henry A. Fribourg, Joe D. Burns, and Larry S. Jeffery

Economical yields of meat or milk from animals grazing perennial pastures require management systems that encourage a good stand of legumes in association with the grass. The problem in managing pastures toward this goal is that white clover (*Trifolium repens* L.) and red clover (*Trifolium pratense* L.) are short-lived in most tall fescue (*Festuca arundinacea* Schreb.) pastures in Tennessee.

White and red clovers must be reestablished in pastures every 2 to 4 years. This renovation process is economically important to livestock managers. Ladino clover-tall fescue pastures in Tennessee have produced as much beef per acre from steers as fescue pastures without clover fertilized with 80 lb N/A. Dairy cows have produced 6 lb more milk per cow per day when grazing clover-fescue than when grazing N-fertilized fescue. In demonstrations, renovated clover-grass pastures have yielded 100 lb more beef per acre than have untreated grass pastures.

Successful renovation of moderately dense fescue sods can be done by overseeding legumes in late winter. However, successful renovation of a dense fescue sod requires suppression of the grass sod until clover seedlings become established. Traditionally, this has been accomplished by disking pastures until a ground cover of 50% grass remained. However, with the disking method, the renovated area is often left in a rough, cloddy condition or rocks are brought to the surface, and extra trips across the field are required if soil conditions are too wet or too dry, or if the sod is very thick. Suppression of the average sod can also be done successfully with moderate to severe grazing. Herbicides such as paraquat (1,1'-dimethyl-4,4'-bipyridinium dichloride), glyphosate (*N*-(phosphonomethyl)glycine), and dalapon (2,2-dichloropropionic acid) are also effective in suppressing grass sods.

In this paper, we shall summarize the results of several experiments where clover was established in thick tall fescue sods following mechanical or chemical sod suppression, and the extension programs and farmer applications on fescue renovation which either accompanied or followed the research activities.

RESEARCH

Materials and Methods

Sod suppression experiments were conducted at Spring Hill and Greeneville from 1975 through 1977, and at Knoxville in 1977. Five different soil types were involved. In 1975, the 5 methods of sod suppression compared to an untreated control on 5 different dates from mid-February through April were: sods disked until 50% destroyed; paraquat applied either broadcast or applied in 4-inch bands with 4 inches between bands at 0.5 lb/A; glyphosate banded at 1.5 lb/A; and dalapon banded at 4 lb/A. In 1976 and 1977, paraquat was also

broadcast at 0.25 lb/A. A Midland Zip seeder was used both to spray herbicides and to drill a seed mixture of 2 lb ladino white clover + 4 lb of red clover per acre. The degree of tall fescue sod destruction was estimated visually in terms of apparent browning, i.e., the percentage of tall fescue leaves which appeared to be dead and, in June, the percentage of the clover stand were estimated and dry matter yields were measured.

An additional experiment was conducted on a dense and vigorous tall fescue sod growing on an eroded clay loam at Knoxville. This sod was clipped at a 1.5-inch height in early March. Following removal, tall fescue sod was (1) untreated or (2) fertilized with 60 lb of N/A; or overseeded by broadcasting (3) 2 lb of ladino clover seed/A or (4) 4 lb of red clover seed/A or (5) 8 lb of Kobe lespedeza (*L. striata* (Thunb.) H. & A.) seed/A; or overseeded with (6) a mixture of the first two or (7) all three legumes, each at the rates used when seeded alone. Each treatment was harvested for dry matter yield with a rotary mower set at 1.5-inch stubble height when growth was 2 to 3 times that tall. Plots without overseeded legumes were harvested starting in early April, and harvesting of plots with legumes started at the end of April, when the seedlings were established satisfactorily.

Results and Discussion

Sod suppression

The degree and rapidity of burndown or browning caused by the herbicides depended on the date when they were applied. At all locations, paraquat caused leaf burn within 2 or 3 days after application, regardless of application date during the period from February to May, as long as some leaves were green.

The systemic action of glyphosate was much slower, requiring 3 to 6 weeks to cause maximum burndown. More time was required for maximum browning to occur following the February and early March applications than when glyphosate was applied in late March or April. The action of dalapon on fescue was very slow, especially when applied before mid-March when temperatures were cool. However, the final degree of burndown from dalapon was approximately equal to that from paraquat or glyphosate.

The conventional treatment of disking until 50% of the fescue was suppressed required 4 to 8 trips across the field, depending on soil moisture. After disking in some experiments, the fescue stand gradually recovered and increased, and 10 weeks after disking, very little difference could be seen between the disked treatment and the control plots. In other cases, a reduction in the fescue stand was still visible 8 months after renovation occurred, and an excellent stand of clover was established.

The 0.5 lb/A paraquat broadcast treatment caused considerably more initial injury to the fescue than did the disked treatment. Sometimes this was more than is desirable. Banded treatments of paraquat and glyphosate gave about equal suppression. The paraquat broadcast at 0.25 lb/A gave good initial suppression, but the effects were short-lived. Depending on application date, glyphosate caused as much or more fescue suppression as did disking. After temperatures were warm, suppression with glyphosate generally persisted longer. With few exceptions, dalapon did not cause fescue suppression equal to disking, and suppression was slow to occur. However, when dalapon was applied in April, the suppression persisted longer than that caused by disking.

Clover establishment

The percentage of clover established in fescue sods at different seeding dates following the different renovation treatments is presented in table 1. The effect of seeding date on clover establishment was pronounced. Early season renovation in late February resulted in a higher proportion of clover in sod than renovations done later. The trend toward poor clover stands with late seeding was evident in the April and May renovations. Weather conditions prevailing after each seeding were very important and had considerable effect on clover establishment success, particularly for March seedings. For example, a poor clover stand at Spring Hill in 1976 for the March 15 seeding was the consequence of an extremely dry April.

TABLE 1.--Average clover stands in June following renovation treatments of tall fescue sods at Greeneville and Spring Hill (3 years), and Knoxville (1 year)

Renovation preparation	Time of treatment and seeding				
	Feb 20-28	Mar 1-8	Mar 9-25	Apr 1-7	Apr 15-May 5
	Percent clover in stand				
None	40†	28	18	20	8
Disking	59	35	32	24	20
Paraquat	52	47	45	27	16
Glyphosate	51	38	27	29	12
Dalapon	44	27	26	17	16

†Range of 67% (10% to 77%), considerably larger than those associated with the other means.

Clover establishment in the control treatment--undisturbed sod--was generally the poorest of all the treatments. Dalapon applied in bands at 4 lb/A resulted in less clover being established than following any of the other sod-suppression methods. Some chemical injury was observed on the clover in areas where dalapon had been sprayed immediately before seeding. Paraquat and glyphosate did not result in visible damage. Disking allowed for adequate clover establishment in some cases and poor establishment in others, but consistently left the land surface in a rough condition for many months.

Both broadcasting and drilling seed in 8-inch rows resulted in good clover stands. Little difference occurred between the two methods, although stands from broadcast seeding were more variable, since they were more subject to environmental influences.

Productivity after renovation

In the spray studies, undisturbed sods produced from about 900 to almost 2,500 lb/A in June following renovation treatments earlier that year. Yields decreased from earlier to later treatment dates, because all sods were clipped to simulate grazing at a 2-inch stubble on the dates when treatments were

applied. In general, the largest yields--mostly of fescue growth--were measured from the undisturbed sods, and the smallest from sods which had been disked, with the chemical sod suppression treatments resulting in yields intermediate between those two extremes. Dalapon and glyphosate in bands and paraquat broadcast resulted in low summer yields when they were applied late in the spring.

In the Knoxville overseeding study, N fertilizer applied in March increased the productivity of undisturbed sod in April and May; 60 lb of N/A increased the cumulative dry matter yield obtained by mid-May about 60% over that obtained when no N was applied. Nitrogen fertilization had little effect on fescue sod productivity from late May through August. Excellent stands of clovers and Kobe lespedeza were obtained in all overseeded plots. The legume stand ranged between 35% and 50% of ground cover in all overseeded plots. Harvesting of plots where legumes had been overseeded started at the end of April, 7½ weeks after overseeding. This agrees with the recommended practice of excluding grazing animals from a renovated pasture until the legume seedlings are well established. Low yields in late April-early May reflected both the small size of the legume seedlings and the fescue sod destruction earlier that spring. However, by the end of July, yields of all renovated sods were equal to or greater than those of fescue alone fertilized with 60 lb of N/A. By the end of summer, the differences were appreciable. Fescue + ladino clover had produced a cumulative yield of 3,155 lb dry matter/A, and tall fescue with 60 lb of N/A, 2,975 lb/A. Fescue + ladino + red clover yielded significantly more than the fescue-ladino mixture, and the fescue + ladino clover + red clover + Kobe lespedeza significantly outproduced all other treatments (3,860 lb/A).

The larger yields of legume-tall fescue mixtures than of fescue alone fertilized with N were associated with increasing percentages of legumes in the harvested forage after June. Ladino clover content increased from 10% of harvested forage in early July to 45% in the grass-ladino mixture in September. Red clover accounted for 35% of the harvested material in July, and 70% in September. When ladino and red clovers and Kobe lespedeza had been included in the overseeding mixture, the September harvest was 75% legume.

Summary

Either paraquat or glyphosate could probably be substituted for disking in a pasture renovation program regardless of when it is initiated; however, *paraquat is the only chemical among those studied which is cleared and labeled for pastures by the Environmental Protection Agency.* It was April or May before temperatures were high enough for banded dalapon to suppress fescue growth, too late for successful renovation. Banded treatments gave adequate fescue and suppression for establishing clover. Paraquat broadcast at 0.5 lb/A suppressed sod more than was necessary or desirable for clover establishment and continued pasture productivity. Banding of spray was preferable to broadcasting at the 0.5 lb/A rate, but broadcasting paraquat at 0.25 lb/A was an acceptable sod suppression treatment for establishing clover.

Pasture renovation in late February or early March resulted in much better clover stands than when renovation was attempted later in the spring. The degree of success in establishing clover depended largely on moisture availability and occurrence of warm periods.

Seeding clover into undisturbed thick fescue sod resulted in poorer clover stands than those obtained where disking or chemical sprays had been used. Disking reduced summer forage yields more than any other sod suppression

method, and left the soil surface in roughened condition.

In general, to obtain long-term improvement of a tall fescue pasture, ladino clover is the preferred legume for inclusion in the sod, although it does not produce as much forage as red clover the first year. The overwintering stolons of ladino clover, the spreading habit of the plant, and its ability to produce seed in large amounts lead to perenniality of stand if grazing pressure, soil fertility, and management are adjusted to the survival needs of the plants. The inclusion of red clover in the renovation mixture can provide for greater first-year legume yield. It usually will not last for more than 2 years; therefore, fescue stands which, after renovation, contain both ladino and red clovers, will usually consist of fescue and ladino clover after 1 or 2 years.

Kobe lespedeza generally grows better in late summer than either of the clovers, and over several years, reseeding stands can be maintained under droughty conditions. With pastures growing on steep, eroded soils, where the surface horizon is high in clay content and available water-holding capacity is relatively low, the addition of Kobe lespedeza seed to the ladino clover + red clover seed in the renovation mixture can lead to greater forage production than where Kobe is omitted.

DEMONSTRATIONS AND EXTENSION PROGRAM

The jingle "2-4-8, Let's Renovate," which refers to the seeding rates of ladino clover, red clover, and Kobe lespedeza (included on droughty soils) is used in the educational program. The slogan has been phrased to emphasize the plants to use and the seeding rates recommended for grass pasture renovation. Hundreds of renovation demonstrations have been conducted on Tennessee farms by county Extension and Soil Conservation Service personnel, and Agricultural Stablization & Conservation Service has renovation as one of the approved cost-sharing practices.

Both broadcast and drilled seedings have been successful during the recommended period. Some of the fields in Tennessee have a striped appearance caused by spraying paraquat in bands in the renovation process; this has been referred to as the Zebra method.

February and March renovations have been most successful. April and May seedings are poor in most instances, due mainly to dry, hot weather following seeding. Fall seeding of clovers in grass pastures has not been as successful as late winter renovation. In addition, most farmers need extra feed in the fall and, therefore, they graze the cattle on fescue in fall and early winter, and renovate in late winter.

Renovation is a continuing on-going program because of the need for clovers in pastures. There are many different methods and machines used in putting clovers back in grass pastures, and they all are successful if the following principles are used:

1. Graze or clip the stubble closely (1 inch).
2. Make soil test and apply fertilizer and lime according to soil test recommendations.
3. Have a 50% fescue stand after chemical or mechanical treatment.
4. Drill or broadcast, and inoculate, the 2-4-8 mixture.
5. Seed between February 10 and March 31.
6. Wait 4 to 6 weeks after seeding before grazing.

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FORAGE PROGRAMS FOR DAIRY CATTLE IN TENNESSEE

By M. J. Montgomery

The old saying that "our cows are better bred than fed" continues to stress to the dairyman that considerable progress can be made in his forage program. One of the main reasons that forage quality should be stressed is because during early lactation, when energy intake is low, milk production needs are high. High-quality forage assists the cow to meet her energy needs earlier in lactation.

Of course, one of the basic components of a forage program for dairy cattle is pasture. This is particularly important where herd sizes are smaller and/or land resources are not suited to hay or silage production. Both perennial and temporary grazing crops have specific roles in dairy operations.

Research at Tennessee using fescue-clover or orchardgrass-clover pastures indicates that maintenance of clover in the pasture is required in the fescue pastures. Thirty to forty percent clover in fescue is needed to maintain production comparable to dry-lot feeding of corn silage and hay. Our data also suggest that high-quality pasture in spring or fall tends to give a production boost to a dry-lot program.

Alfalfa continues to be an important part of the forage program on a large number of Tennessee dairy farms. Considerable research effort has been expended to determine storage and feeding losses of large round bales of alfalfa-orchardgrass hay. The use of a black plastic cover over the top of the bale and elevation of the bale on tires or poles have been the major techniques for decreasing storage and feeding losses. Our data suggest that alfalfa hay stored in large round bales uncovered on the ground results in a loss of 1/3 of the dry matter from field to the cow. Dairymen cannot afford this kind of loss of excellent-quality alfalfa hay even though savings in labor of baling are realized.

Corn silage continues to be the major stored forage fed to dairy cattle in Tennessee. Production increases have been realized when corn silage has been supplemented with either alfalfa hay or alfalfa low-moisture silage. Increased consumption of dry matter is the major reason. As a result, many dairymen harvest the first cutting of alfalfa as low-moisture silage and make hay of the remaining cuttings.

Corn silage has been the basis of comparison of a large number of other crops. Our data indicate that bird-resistant grain sorghum contains enough tannin that both intake of dry matter and milk production are reduced. Some of the taller growing forage sorghums have outyielded corn in silage production, but have not measured up in milk production. Our data indicate a possible binding of such a significant amount of the nitrogen in the acid detergent fiber that a higher protein grain mixture must be fed to maintain production.

Wheat silage has been used by some dairymen to supplement forage intake during the summer. Our data indicate that cows prefer corn silage to wheat and also produce more milk on corn compared to wheat. Formic acid treatment

of wheat silage results in a slight increase in animal performance, whereas use of the acid on corn silage shows no benefit at all.

Long-term feeding of corn silage or corn silage plus hay on concrete lots has caused increased feet and leg problems and loss of cows at calving following complete confinement. Increased weight gains during the dry period on the high-energy ration are no doubt part of the reason for complications.

Green chopping of perennials or annuals for additional forage intake is limited in our state. Our research has shown that using green chop or pasture as a supplement results in increased milk production of cows confined to dry lot. The quality of the pasture or green chop is extremely important.

The use of a complete-ration feeding concept--mixing of forage and grain--is increasing in Tennessee. It provides a way to handle large groups of cows while also meeting their nutritional requirements. The use of mixing wagons and trucks has increased tremendously. Our data suggest that, for a 75-pound/day production level for Holsteins, 2 parts corn silage to 1 part grain (as-fed basis) plus 10 pounds of hay will meet the production requirements. Hay is needed to prevent digestive problems and fat test depressions.

Dairy cows may be fed in a large number of ways, depending on the resources available. No doubt in the future, with the increased demand for feed grains for human consumption, we will continually need to emphasize the importance of forage quality for supplying the nutritional needs of dairy cattle.

SOME ROLES OF ALLELOPATHY IN PASTURE AND FORAGE CROPS

By Elroy L. Rice

Molisch (1937) coined the term "allelopathy" to refer to biochemical interactions between all types of plants, including microorganisms. His discussion indicated that he meant the term to cover both detrimental and beneficial reciprocal interactions. I will use the term in this sense in the discussion that follows.

The suspicion that allelopathy occurs goes back at least as far as Theophrastus. In his "Enquiry into Plants," written sometime prior to 285 B.C., Theophrastus pointed out that chickpea does not reinvigorate the ground as other related plants do but "exhausts" it instead. Moreover, "it destroys weeds, and above all and soonest caltrop." Pliny in his "Natural History" written in the first century A.D. has many references to apparent allelopathic effects.

ALLELOPATHIC INTERACTIONS AMONG PASTURE AND FORAGE PLANTS

Patterning of Vegetation

Cooper and Stoesz (1931) observed the fairy-ring pattern of the prairie sunflower, which is due to a pronounced reduction in plant numbers, size, and inflorescenses in the center of the clone. Curtis and Cottam (1950) observed the same phenomenon and after numerous experiments concluded that inhibition inside the clones resulted from autotoxins produced by decay of dead plant parts of the sunflower. Wilson and Rice (1968) observed striking patterns of distribution of herbaceous species around individuals of the annual sunflower in revegetating old fields. Measurements of various habitat factors suggested that the zonation was not likely due to competition. Small amounts of decaying sunflower leaves, leachates of tops, and exudates of roots were tested against several species which grow in the same general areas. The species which are stunted near sunflowers in the field were inhibited in all tests, whereas those species which do well near the sunflowers were not stunted in most tests. Thus, field observations were well correlated with results of laboratory tests of allelopathic effects of sunflower.

Muller, Muller, and Haines (1964) became intrigued with the striking patterns of vegetation in and around patches of *Salvia leucophylla* and *Artemisia californica*. Virtually no herbaceous species occur within the shrub stands, a bare zone approximately 1-2 m wide occurs around the stands, a zone about 3-8 m wide containing stunted grasses occurs around the bare zone, and this is surrounded by the normal grassland. After numerous experiments and tests, they eliminated predation, edaphic factors, and competition as the basic causes of the zonation. Tests indicated that leaves of *Salvia* and *Artemisia* produce volatile chemicals which inhibit growth of roots of wild oat seedlings and other plants. Several terpenes were identified and later detected in the field

also, and these were shown to be adsorbed on soil and to remain in an active state. Seeds and seedlings in contact with the terpene-containing soil extract some of the terpenes by solution in cutin which is in direct contact with the soil particles.

Chamise (Adenostoma) is almost devoid of herbs within the shrub zone and a zone about 1 m wide occurs around the chamise and is almost devoid of the dominant grass in the grassland, wild oats (Avena fatua). After numerous experiments McPherson and Muller (1969) concluded that water-soluble inhibitors produced by the tops of the chamise are primarily responsible for the failure of herbs to grow in the shrub zone and for the failure of the grass zone plants to grow in the border zone. Subsequent work by Tinnin and Muller (1971) caused these workers to conclude that the herb species which occur in the border zone are prevented from growing in the grassland primarily due to toxins present in the dead residue of wild oats.

Several years ago, James Rasmussen and I observed that Sporobolus pyramidatus, dropseed, often expanded the size of its stands in the University of Oklahoma Golf Course from a few plants to rather large areas in a short time in spite of the heavy stand of bermudagrass and occurred in virtually pure stands itself. As the dropseed stands spread, the dropseed died out partially in the center of the stand and appeared to be less vigorous in vegetative growth and inflorescence production than around the margin. Similar patterns were found in the Wichita Mountains Wildlife Refuge in southwestern Oklahoma in natural buffalograss areas. S. pyramidatus is a small grass, usually attaining a height in our area of no more than 1 dm or so even in flower. Thus, it shades other plants very little. No differences were found in several physical and chemical factors measured in the dropseed stands and outside them. Bermudagrass and buffalograss grew better in soil collected in July from the dropseed stands than in soil from the bermudagrass stands, indicating there was no deficiency of minerals in the soil in dropseed stands. Soils collected in January, however, from within the dropseed stands significantly inhibited growth of the same two species but not Sporobolus. These results indicated a toxic effect of the soils closely associated with dropseed and eliminated any competitive mechanism associated with the dropseed plants. Studies were undertaken next to determine the sources of the toxins in the soil of the dropseed plots. Leachates of leaves, exudates of roots, and decaying root and shoot material of dropseed were tested against buffalograss and bermudagrass. The leachate was generally not inhibitory to the test species, but the decaying leaf material was inhibitory to seed germination and seedling growth of both species. Decaying root material and root exudates significantly inhibited both seed germination and growth of bermudagrass but not of buffalograss. The evidence seems clear that dropseed spreads rapidly into heavy sods of bermudagrass and buffalograss because it produces toxins that are exuded from living roots or diffuse from decaying roots or shoots and inhibit seed germination and growth.

Mustard, Brassica nigra, forms pure stands that have invaded slopes in the annual grasslands of coastal southern California. All the species involved are annual plants that pass the dry summer and early fall as seeds, and the supply of grass seed is plentiful both inside and outside the mustard stand (Bell and Muller, 1973). Seed germination occurs during a 2- to 3-day period at the time of the first significant winter rain. There is no competition during this period in the grass or mustard area because only the dead parts of the previous year remain. Nevertheless, the grass seeds germinate in great density in the

grassed area, but not at all in adjacent areas in the mustard stands despite plentiful supplies of moisture and grass seeds. After many experiments, Bell and Muller concluded that the establishment and maintenance of mustard in virtually pure stands is the result of toxins in rainwater leachates from dead stalks and leaves of the mustard crop of the previous year.

Newman and Rovira (1975) investigated chemical interactions between eight species from a permanent British grassland, four grasses and four forbs. Leachates of donor pots of each species were tested against each of the eight species in receiver pots with extra nutrients being added on a regular schedule. Leachates of all donor species were significantly inhibitory compared with controls having no plants in the donor pots. Analysis of some of the plants for N, P, and K showed that the growth reductions were not due to nutrient deficiency. Four of the species were inhibited more by pot leachates of their own species than by leachates of other species, and all others showed the opposite response except one which was intermediate. Subsequent field observations indicated that the most autoinhibited species are normally found as isolated individuals, or a few individuals in a group, but not in pure stands. The three species which were alloinhibited are all capable of dominating a permanent grassland. The authors concluded that the operation of autoinhibitory exudate effects may turn out to be a key process in controlling species diversity in grassland.

In a study in the short grass prairie of Colorado, Bokhari (1978) found that both blue grama (*Bouteloua gracilis*) and western wheatgrass (*Agropyron smithii*) exhibited autotoxicity. He reported that both appear to grow better in a mixture with other species. These observations support the conclusions of Newman and Rovira.

Allelopathic Effects of Forage Crop Plants

Clover sickness has been known in Europe since the 17th century. Tamura et al. (1967, 1969) stated that it has been well known that red clover (*Trifolium pratense*) exhibits allelopathy against itself. In an effort to explain the causes of the autotoxicity, these workers isolated and identified nine inhibitory isoflavonoids or related compounds from tops of red clover. Subsequently, Chang et al. (1969) found that all the identified isoflavonoids inhibited red clover seedling growth equally in nutrient solution, with inhibition occurring even at a concentration of 10 ppm. These compounds also inhibited seedling growth of red clover in soil over an entire 10-wk trial period.

Careful extraction resulted in the isolation of no isoflavonoids from "sick" soil. Relatively high amounts of several phenolic acids were isolated from the soil, however, and were subsequently found to result from decomposition of the isoflavonoids present in red clover. Chang et al. (1969) concluded that "clover sickness" results, therefore, from the exudation by red clover of isoflavonoids which decompose to phenolic compounds which accumulate in soil to toxic levels.

Katznelson (1972) investigated the clover sickness problem resulting from continuous growth of berseem (*Trifolium alexandrinum*) or Persian clover (*T. resupinatum*). He concluded that nematodes may be the cause of the problem in Persian clover, but not in berseem. Berseem in plots previously cropped to berseem had much lower phosphorus levels in the leaves than in control plots, and the nutritional imbalance could not be corrected by fertilizer applications. He concluded, therefore, that the berseem soil sickness may be due to

allelopathic factors which are directly or indirectly responsible for the decline in "P-promoting" microorganisms.

Lykhvar and Nazarova (1970) studied the growth of several species of legumes and maize in pure and mixed cultures and reported that beneficial effects of legumes grown in mixed cultures with maize depend on specific varieties of the legume species. Many varieties gave detrimental results in mixed cultures indicating allelopathic effects. As a consequence of these experiments, new varieties of legumes were developed specifically for use in mixed cultures with maize or other crop or forage plants. This type of research seems to me to hold excellent promise in agriculture.

Rakhteenko, Kaurov, and Minko (1973) found that substances were exuded by roots of pea (Pisum arvense) and vetch (Vicia villosa) which stimulated photosynthesis and absorption of ^{32}P by barley and oat plants. The exudates also stimulated uptake of N, K, and Ca from nutrient solution by the cereals. In contrast, active substances exuded from the roots of the cereals inhibited the same processes in the two legumes.

Zabyalyendzik (1973) investigated the interactions of buckwheat (Fagopyrum), lupine, mustard, and oats in field and greenhouse experiments. He reported that yields of tops of buckwheat were 30%-35% and grain yields 12%-35% greater in crops with other components than in pure stands. Root exudates of lupine and mustard stimulated growth and development of buckwheat, but root exudates of oats inhibited growth and yield of buckwheat. Root exudates of buckwheat stimulated growth of oats, whereas they inhibited growth and yield of lupine.

Sajise and Lales (1975) studied interactions between cogon (Imperata cylindrica) and pencil flower (Stylosanthes guyanensis), using a root divider technique. They found that allelopathic activity of cogon accounted for a 38% reduction in the growth of pencil flower, and that pencil flower inhibited cogon growth also during the first 8 mo after transplanting.

Patrick, Toussoun, and Snyder (1963) demonstrated clearly that toxic decomposition products of rye residues are produced under field conditions, Chou and Patrick (1976) identified nine compounds produced in decaying rye residue. All were phenolic compounds, and most were found to be inhibitory in the lettuce seed bioassay.

It has been observed for a long time in Senegal in west Africa that growth of sorghum is decreased markedly following sorghum in sandy soils, slightly in soil with kaolinite clay, and none in soils high in montmorillonite (Leon, 1976). Leon observed the same results with sorghum seedlings when roots or tops of sorghum were added to sandy soil in laboratory experiments. No inhibition resulted when the residues were added to soil high in montmorillonite. The same results occurred under sterile conditions. Moreover, water extracts of roots or tops inhibited growth of sorghum seedlings similarly. Leon found that inoculation with Trichoderma viride or an unknown species of Aspergillus eliminated the inhibitory effects of aqueous extracts of roots of sorghum on sorghum seedling growth in a short time. In subsequent experiments using uninoculated, nonsterile field soil, several weeks were required to detoxify the soil after addition of root residues of sorghum. He concluded that the native microflora in the sandy soils of Senegal were not able to detoxify the soil fast enough to prevent inhibition of subsequent crops of sorghum in the same soil.

Attempts to establish the legume Desmodium intortum in pastures of bigalta limpograss (tetraploid Hemarthria altissima) in Hawaii have been unsuccessful. After a very thorough investigation, Young (1979) concluded that inhibition of intortum by bigalta limpograss is allelopathic. The inhibitors

come chiefly from root exudates and decaying root residues, and inhibit nitrogen fixation in addition to growth of intortum.

Allelopathic Effects of Weeds on Crop Plants

Bieber and Hoveland (1968) reported that water extracts of peppergrass (*Lepidium virginicum*), *evening primrose* (*Oenothera biennis*), and crabgrass were toxic to seed germination of crownvetch (*Coronilla varia*). Peppergrass residues incorporated in the soil for 10 wk were toxic to germination of crownvetch seed also.

Bell and Koeppe (1972) concluded that inhibition of growth of corn by giant foxtail (*Setaria faberii*) is due in part to allelopathy.

Einhellig and Rasmussen (1973) found that extracts of leaves of curlydock (*Rumex crispus*) were inhibitory to corn and sorghum. It was observed in Spain that nutgrass (*Cyperus esculentus*) interferes strongly with corn growth, and Tames, Gesto, and Vieitez (1973) demonstrated that extracts of the tubers contained several compounds that inhibited seed germination of numerous crop plants.

Canada thistle is a pernicious week in field crops, and Bendall (1975) found that extracts of the roots and foliage of this plant and decaying roots and tops were inhibitory to seed germination of subterraneun clover and to seedling growth of this legume and two grasses.

Naqvi (1972) observed that Italian ryegrass (*Lolium multiflorum*) suppresses germination and growth of many species in its vicinity. Later, Naqvi and Muller (1975) found that leachates of living tops, leachates of soil previously occupied by Italian ryegrass, and decomposing residues were toxic to seedling growth of oats, bromegrass, clover, and other species.

Common milkweed (*Asclepias syriaca*) is a major weed in north central and northeastern United States and Canada, and was found to reduce the yield of sorghum significantly in field tests in Nebraska, according to Rasmussen and Einhellig (1975). Subsequently, these investigators found that aqueous extracts of milkweed leaves significantly inhibited growth of sorghum seedlings, and reduced concentrations of the extracts resulted in proportional increases in yield.

Kossanel et al. (1977) demonstrated that water solutions in which lambsquarter (*Chenopodium album*) previously grew and water extracts of ground roots of this species inhibited growth of corn.

Allelopathic Effects of Crop Plants on Weeds

Peters (1968) observed that both thin and dense field stands of 'Kentucky-31' fescue (*Festuca arundinacea*) are often relatively free of weeds. Subsequent investigations with extracts, split-root-system experiments, and sand cultures demonstrated that toxic materials were produced by fescue, exuded from the roots, and inhibited growth of test species such as *Brassica nigra*.

Markova (1972) reported that oats suppressed growth of *Erysimum cheiranthoides*, due at least in part to allelopathy.

Putnam and Duke (1974) screened 526 accessions of cucumber and 12 accessions of 8 related *Cucumis* species for allelopathic activity against a forb, *Brassica hirta*, and a grass, *Panicum miliaceum*. One accession inhibited indicator plant growth by 87% and 25 inhibited growth by 50% or more. They concluded that incorporation of an allelopathic character into a crop cultivar

could provide the plant with a means of gaining a competitive advantage over certain important weeds.

Fay and Duke (1977) screened 3,000 accessions of the USDA World Collection of Avena spp. germplasm for their ability to exude scopoletin, a naturally occurring compound shown to have growth-inhibiting properties. Twenty-five accessions exuded more blue-florescing material, characteristic of scopoletin, from their roots than did Avena sativa cv. 'Garry', a standard oat cultivar. Further analysis indicated that four accessions exuded up to three times as much scopoletin as 'Garry' oats. When one of these was grown in sand culture for 16 days with a wild mustard (Brassica kaber), growth of the mustard was significantly less than that which occurred when the mustard was grown with 'Garry' oats. The mustard plants grown in association with the toxic accession were chlorotic, stunted, and twisted, indicating a chemical effect rather than simple competition.

The future looks bright for the breeding of crop and forage plants allelopathic to some of the major weeds of a given locality. It should be possible also to select crop and forage plants for resistance to allelopathic agents produced by important weed species. Such developments could markedly reduce the requirements for commercial herbicides.

There are many other phases of allelopathy which are important to pasture and forage plants, but space does not allow discussion of them here. For further information, see Rice (1974, 1979). Numerous other review articles on allelopathy are cited there.

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LONG-TERM FERTILITY STUDIES AS RELATED TO PASTURES AND SMALL PLOTS: HOW PRECISE ARE SMALL-PLOT DATA FOR PREDICTING PASTURE NEEDS?

By William G. Blue

The question of interpretation of small-plot data for fertilizer recommendations for pastures has been of concern to me during my entire 30 years in Florida. It is obvious that there is some potential for reutilization of nutrients by plants under a grazing system because of return of nutrients in animal excreta; in contrast, there is very little potential under a harvest system where all forage is removed. Mott (1974) reviewed the subject of nutrient recycling; he generally concluded that the animal is effective in the recirculation of nutrients in the soil-plant-animal system. Peterson et al. (1956a, 1956b) indicated that the largest returns of P and K occurred under conditions of high stocking rate and long periods of grazing. The effectiveness of a nutrient would depend on its rate of loss from the soil. They suggested that maintenance fertilization with P might be adjusted downward and that any adjustment for K should be postponed for several grazing seasons.

The macronutrients N, P, and K are of major interest in considering the transfer of data from harvested plots to large-scale pastures because of the relatively large quantities of nutrients required and their high cost. Very few comparisons have been made with N in Florida. However, the average quantity of N used per hectare for pastures represents no more than one-eighth to one-fourth of that needed for maximum yield response on harvested plots. Thus, N utilization by grazed forages is likely not adversely affected by excessive N. Many studies have been done with harvested plots. Apparent N recovery normally ranges from 50% to 80% of the N applied. Nitrogen leaching from perennial grass sods when it is applied during the period with conditions suitable for plant growth does not appear to be a major problem (Blue and Graetz, 1977). Denitrification does occur, particularly in the Spodosols, and is likely of more importance than leaching.

Phosphorus is bonded very strongly and in large quantity by Ultisols, primarily as complexes with Al and Fe. It is held relatively weakly by acid Spodosols and will leach from the surface soil. When the Spodosols are limed, P is retained much more efficiently. Phosphorus uptake by forage plants from a newly fertilized virgin Ultisol may be as low as 5% to 20% depending on the rate of P applied. Uptake from the Spodosol will be higher. In any case, P will accumulate in the soil, and it retains some availability. Obviously, more P is removed at a given yield level under a harvest system than under grazing. Studies at the Beef Research Unit, Gainesville, Florida, with a Spodosol, gave apparent P recovery of 136% where forage was grazed, based on the annual rate of P applied, and 91% under a forage harvest system (Blue and Gammon, 1963). This difference could be much larger for an Ultisol.

Potassium is not subject to loss by volatilization and is retained efficiently by some soils. It is needed in relatively large quantities by forage plants; on highly weathered soils, much of this K requirement must be supplied

by fertilizers since these soils do not contain large amounts of K and K is not retained at high concentrations in the soil. Since K does not volatilize, is usually not fixed, and the highly weathered soils contain limited amounts, K utilization under forage harvest and grazing systems has probably received more attention than have N and P.

In contrast to the experiment with N-fertilized grass, another experiment involved grazing and forage harvest of white clover (Trifolium repens L.) and Pensacola bahiagrass (Paspalum notatum Flugge) (Blue and Gammon, 1966). Symbiotic N fixation by the clover was the driving force for forage production. Potassium was applied annually in November at 74 kg/ha/year. Apparent recovery of applied K in forage from grazed plots averaged 192% over a 6-year period; K recovery from harvested plots averaged 83%, but it exceeded 100% during the first 2 years and was only 30% during the sixth year. Extractable soil K was also much less from harvested plots than from grazed plots.

White clover acts as an annual in Florida and must reestablish from seed. Its initial development is slow, and seedlings apparently require a higher K concentration in the surface soil than that available from the fertilizer and residual soil K following forage harvest. After the 6-year experimental period, the K rate for harvested plots was increased to 148 kg/ha/year, with one-half applied in November and one-half in April. Growth of white clover and amount of N fixed symbiotically were increased; apparent recovery of applied K increased from 70% to 100% through a subsequent 3-year period.

The fact that K uptake by plants under grazing from the Spodosols usually exceeded the quantity of K applied annually indicates recycling of K in the soil-plant system. If the soil retained K, this could eventually result in reduced K application. In fact, the fertilizer K requirement for a given forage yield level is substantially less under grazing than for a forage harvest system. However, K retention in Florida soils, including the poorly drained flatwoods, Spodosols; deep, well-drained ridge soils, Entisols; and the finer textured west Florida Ultisols, is limited almost regardless of soil treatment. These soils have small quantities of inorganic colloids; these are dominated by hydroxy Al and Fe, and low cation exchange capacity (CEC) silicate clays. The CEC of the soil is dominated by organic matter which is also usually present in low concentration. Furthermore, while organic matter is known to have a high CEC when measured by 1N NH_4OAc (pH 7.0), its CEC is pH dependent. At soil pH 7.0, the CEC is approximately 2 meq/100 g of soil for each percent of organic matter in the soil. When soil pH is below 4.5, the CEC from organic matter approaches zero.

Studies by Khomvilai and Blue (1977) showed that the effective cation exchange capacities (ECEC), the sum of exchangeable Al, H, Ca, and Mg at the existing soil pH, of a virgin Florida Ultisol and Spodosol were 3.4 and 1.4 meq/100 g of soil, respectively (Table 1). When these soils were limed to pH 7.0, ECEC values were 6.6 and 4.0 meq/100 g of soil, respectively. Exchangeable Al and H were dominant cations in the unlimed Ultisol and Spodosol. When these soils were limed, exchangeable Al and H decreased; the increase in ECEC was due to increasing quantities of exchangeable Ca or Ca and Mg, depending on the composition of the liming material. Exchange sites on organic matter have greater affinity for divalent cations such as Ca and Mg than for monovalent cations such as K (Broadbent and Bradford, 1952). In the studies by Khomvilai and Blue, most of the K from KCl was in the saturation solutions from Myakka fine sand (Spodosol) and roughly half in the solutions from Red Bay fine sandy loam (Ultisol) regardless of amount of $CaCO_3$ applied (Table 1). This K is

Table 1. Cation Exchange Characteristics of a Florida Ultisol and Spodosol

Lime Source	Lime Rate	pH (H_2O)	CEC†	ECEC‡	Potassium applied§ None	KCl	K_2CO_3
	meq/100g		meq/100g		Potassium in saturation soil solution, meq/liter		
		Red Bay fsl (Ultisol)					
Control	0	5.1	5.3	3.4	0.7	11.1	2.0
$CaCO_3$	2	6.0		5.2	0.3	11.8	3.2
$CaCO_3$	4	7.0		6.6	0.4	12.4	3.4
Dolomitic	2	7.0		4.0	0.2	6.5	0.6
Dolomitic	4	7.0		4.5	0.1	6.4	0.8
		Myakka fs (Spodosol)					
Control	0	5.1	3.4	1.4	0.2	19.1	2.2
$CaCO_3$	2	6.0		2.6	0.1	21.2	4.7
$CaCO_3$	4	7.0		4.0	0.2	20.6	6.9
Dolomitic	2	6.7		2.4	0.1	21.2	4.4
Dolomitic	4	6.8		3.2	0.2	17.2	3.9

†CEC was determined by 1 N NH_4OAc (pH 7.0).

‡ECEC equals the sum of exchangeable H, Al, Ca, and Mg.

§Potassium was applied at a rate of 1 meq/100 g of soil.

subject to leaching. Less K was in solution from soils limed with dolomitic lime. The addition of KCl to the soil will tend to depress pH slightly and increase competition with Ca and Mg for a reduced number of adsorption sites. The addition of K_2CO_3, in contrast, tends to raise soil pH, increase pH-dependent exchange sites, reduce competition by Ca and Mg, and increase K retention. Studies at the Beef Research Unit, Gainesville (Blue, 1977) with a Spodosol showed the same quantity of exchangeable K in a limed soil after 20 years of annual K fertilization with all forage grazed as in the virgin soil at the beginning of the experiment (Table 2). Approximately 1450 kg/ha of K were applied during the 20-year period. One might expect some accumulation of K in the Ultisol under a grazing system, or that the annual rate of application could be reduced since K will accumulate to a higher level in this soil.

In summary, in long-term studies in Florida with Spodosols, similar forage yields have been produced under grazing and forage harvest systems. A higher rate of K fertilizer was required for the forage harvest system. Apparent K recovery in forage from clipped plots has been from 70% to 100% of the K applied. Apparent K recovery in forage under grazing appears to be on the order of 190%. These values indicate considerable recycling of K where forage is harvested by grazing. In practice, it appears that approximately one-half the K rate needed for harvested forage is adequate for pastures. However, it has not been possible to reduce the level of K fertilization below these rates because the Spodosol retains K poorly, especially when KCl is used as the K fertilizer material. Ultisols retain more K and some reduction in K rate under grazing might be possible.

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Table 2. Exchangeable Potassium in a Virgin Florida Spodosol and through 20 Years of Liming and Regular Fertilization †

Year	Soil pH	Exchangeable K
		kg/ha
1951	4.9	50
1965	6.1	68
1967	5.5	106
1969	6.5	83
1971	6.4	91
1972	6.3	50

†Potassium applied during the 20-year experimental period was 1450 kg/ha.

GASEOUS AMMONIA LOSSES AND GAINS IN A SOIL-PLANT SYSTEM

(Abstract)

By L. A. Harper, V. R. Catchpoole, and I. Vallis

Large amounts of nitrogen are known to be lost from grazed pastures, but the importance of different loss mechanisms requires quantification. This research determined, using turbulent transport techniques, the amount of nitrogen lost as ammonia to the atmosphere from a grazed tropical pasture (*Setaria anceps*) at Samford Experiment Station, Queensland, Australia. Diurnal, seasonal, and annual transport of aerial nitrogen compounds were studied in relation to soil, plant, animal, and climatic influences. Large increases in net outward aerial ammonia flux occurred from the sward within 4 to 48 hours after urea fertilizer application, depending on soil water content and weather conditions. The rate at which the large outward fluxes diminished with respect to time also varied with soil and weather conditions. The highest diurnal ammonia fluxes generally took place during periods of highest solar insolation; however, we found periods during mid-day with both positive and negative fluxes after the influence of fertilizer amendment (i.e., high soil mineral nitrogen) had diminished.

There were two periods each day of net flux of ammonia into the soil-plant system (influx). These periods usually lasted less than 2 hours and occurred around sunset and sunup. The influx periods did not correlate with any measured soil or microclimatic factors or with dew accumulation or evaporation; however, influx periods occurred more frequently when the soil was dry. We attribute the influx to possible absorption by leaves attempting to satisfy the plant's ammonia need for amino acid synthesis. The influx periods occurred during low transpiration periods which decrease nitrate or ammonium supply to the leaf through the transpiration stream. Unfortunately, we were not able to determine the maximum magnitude and period length other than our 2-hour sample period. Also, there is no practical field method for distinguishing between ammonia absorption by the soil and grass sward.

We found ammonia losses from cattle urine patches to be significant but not of major importance. Ammonia volatilization showed high loss rates in the first 24 hours, declining to relatively low rates within 3 to 4 days; the highest fluxes occurred in daytime. There was no detectable flux after 6 weeks. We calculated from these experiments a loss of 20 kg N/ha per year based on animal consumption and excrement rates, roughly equivalent to 3 percent of all fertilizer nitrogen applied.

The majority of aerial ammonia losses occurred within 14 days after fertilizer application. Losses of 12, 42, 13 and 9 percent of applied fertilizer nitrogen occurred during the summer, autumn, winter, and spring seasons, respectively. Nineteen percent of fertilizer nitrogen applied was lost within 14 days, whereas an average of 5 percent was lost during the period after 14 days to the next application. Individual losses during the latter periods

were 9, 26, and 13 percent during autumn, winter, and summer seasons. An average of 7 percent was gained by the soil-plant system during the spring season.

We calculated that 24 percent of the applied fertilizer nitrogen was lost by ammonia volatilization. Another 3 percent was attributed to ammonia losses from cattle urine patches. We feel the practical estimate of ammonia volatilization losses to be between 25 to 30 percent of applied fertilizer nitrogen for this cattle-forage system.

FORAGE-LIVESTOCK DEMONSTRATIONS IN KENTUCKY: AN EXTENSION TOOL

By Garry D. Lacefield, Duane Miksch, Ron Parker, and Monroe Rasnake

Demonstration of practices on producer farms has been an effective tool in facilitating adoption of recommendations obtained through research. Demonstrations have been used successfully to show improved practices and procedures in agronomy, animal science, veterinary science, and other agricultural sciences for many years. At the University of Kentucky College of Agriculture, demonstrations concerning forage production and utilization have included soil testing, lime and fertilizer application, species and variety selection, renovation, stockpiling, grazing systems, haymaking and preservation, and hay feeding techniques. Likewise, extension specialists in animal and veterinary science have used demonstrations in many areas: implanting, grain on grass, preconditioning, calving seasons, dehorning, castrating, worming, vaccinating, pregnancy determination, parasite control, and performance testing. The impact of successful demonstrations on acceptance of specific recommendations suggested the need to coordinate multiple practices in selected demonstration herds. As a result comprehensive cow-calf management demonstrations were implemented in 1976, with an overall objective of demonstrating practices that are feasible and identifying those that are not.

This interdisciplinary team approach by extension specialists in providing cow-calf management recommendations has been well received by Kentucky cattle producers. Specialists in beef cattle, agronomy, and veterinary science are serving as primary team members, with support from specialists in farm management, agricultural engineering, entomology, and marketing.

County agents and veterinary practitioners provide avenues for translating University recommendations to meet individual needs. Management decisions in a cow-calf enterprise are economically critical because the ratio of investment to profit-potential is small and uncertain. New practices must be carefully evaluated and well demonstrated before being accepted.

Herds for comprehensive cow-calf management demonstrations typically consist of 30 to 100 cows. They are selected on the basis of presently employing a minimum of recommended practices, and a willingness to introduce more. Extension specialists, county agents for agriculture, local practicing veterinarians, and cow-calf producers work together to incorporate a maximum number of recommended practices accepted as feasible for each cooperating herd.

Practices demonstrated include but are not limited to: individual animal identification, proper nutrition, performance testing, soil testing, pasture renovation, genetic selection, forage harvesting and feeding, corral design, worming, implanting, external parasite control, immunizations, dehorning and castrating, pregnancy examination, limited calving season, and marketing.

As an incentive to the cooperator to adopt recommendations, as many services and supplies as possible are provided without charge. Grants from industry of animal-health products, agricultural chemicals, fertilizer materials, identification aids, feed supplements, forage seeds, and equipment

allow rapid management adjustments.

Each demonstration is designed for a five-year period, with the major emphasis on material inputs coming in the first three years. Termination of the demonstration can occur at any time during the five-year period at the discretion of either the cooperator or the management team. Results of adopting recommended practices are assessed through farm analysis comparison with similar enterprises.

BEAUCHAMP-ALEXANDER FARM: AN EXAMPLE

The Beauchamp-Alexander farm has been the site of a comprehensive cow-calf management demonstration since 1976. Extension specialists from several departments have worked closely with Russell Beauchamp and his son, Paul, and son-in-law, Ova Alexander, in incorporating recommended management practices into their beef-forage program.

The Forage Program

The forage program on this farm is based on cool-season grasses and legumes. Fescue is the primary grass, although orchardgrass and timothy are also used. Red clover is the dominant legume. Other legumes which are used to a lesser extent include ladino clover, alfalfa, and lespedeza. Corn is usually grown on 30 to 50 acres and used in the feeding program.

The first step in improving the forage program was soil testing. Following soil testing of the entire farm, a fertility program was planned. Nitrogen was the limiting factor on grass fields. Soil test results showed phosphorus to be the most limiting factor for legume and grass-legume mixtures, with many fields needing lime and potash. Fertilizer, based on soil test results, is applied at establishment and during the productive life of the stand. Nitrogen has been used on selected fescue fields in August for stockpiling.

The addition of legumes (red clover) through renovation has been the most noticeable change in the forage program. Approximately 80-100 acres are renovated each year. Several methods of renovation have been successfully used. The legumes have improved both quality and quantity of forages produced. Hay yields have been increased from approximately 1 ton/acre to over 3.5 tons/acre. Increased emphasis on hay quality has resulted in improved cow herd nutrition. A rigid cutting schedule is practiced, with hay plants being harvested in an early flowering stage. All hay was stored in conventional square bales when the demonstration began. The addition of a large round baler has decreased the labor requirement. However, both square bales and large round bales are used. Large round bales are fed in racks to reduce waste. Pasture clipping, rotational grazing, and chain harrowing, along with pest control measures, are also practiced. Approximately 100 acres of woodland was cleared and seeded to pasture in 1979.

The Cow Herd

The original cow herd consisted of 95 Hereford cows, with Hereford bulls used exclusively. A crossbreeding program has been initiated with Angus bulls to produce black-white-faced (BWF) calves for sale and replacement heifers. The first crop of BWF calves was produced in 1978, and the first group of BWF

replacement heifers was bred in the spring of 1979. The cow herd presently consists of 110 brood cows and 50 yearling heifers exposed for breeding in May, 1980. Replacements will be selected from heifers in the group which conceive early. Prior to the beginning of the demonstration, herd bulls had been maintained with the cow herd year-round. In 1977 calves were born in all months of the year with the exception of January and December. By controlling the time bulls are with the cows and culling open cows, planned calving seasons have become a reality in this herd. Two calving seasons, spring and fall, are currently used. In 1979, 90 percent of the spring calving cows calved in February and March, while 88 percent of the fall calving cows calved in September.

A noticeable change has occurred in productivity per cow. In 1976, approximately 65 percent of cows in the herd weaned a live calf. Through better nutritional programs, rigid culling, and incorporation of definite calving seasons, this has been greatly improved. Seventy-seven and 87% of cows exposed for breeding were diagnosed pregnant in 1978 and 1979, respectively. Although benchmark weaning weights were not obtained, average weaning weights have been estimated to have increased by a minimum of 50 pounds.

Some calves have been fed to heavier weights after weaning on this farm. Improved ration formulation, primarily incorporation of proper supplementary protein, has improved efficiency of gain in these cattle. Improved forage production and incorporation of definite calving seasons has made it much easier to feed the cow herd according to stage of production and nutritional needs. Individual identification of all cattle forced use of dust bags for fly control, and addition of new cattle-handling facilities are other practices which have been helpful management tools on this farm.

Herd Health

Health maintenance benefits are difficult to measure apart from nutritional management benefits. Major adjustments in both have had a dramatic effect on productivity. Pinkeye has been the only observed infectious disease in this demonstration herd. Any reduction in the incidence of pinkeye must be attributed to improved face fly control and pasture clipping. Reduction in severity of pinkeye cases can be credited to prompt treatment.

All adult cattle have been tested for brucellosis and tuberculosis. The immunization program currently includes vaccination for clostridial diseases (*Cl. chauvoei-septicum-novyi-sordelli-perfringens*), leptospirosis (*L. gryppotyphosa-hardjo-pomona*), IBR-PI_3, and BVD. None of these diseases were or are known to be present in the herd. Vaccination is directed against potential losses from any of these infections.

Internal and external parasites were a recognized problem in the herd prior to starting the demonstration. Clinical gastrointestinal parasitism (wormy cattle) had been diagnosed. A routine worming program was initiated and has been continued. Lice infestation was evident the first winter of the demonstration and a single pour-on application of insecticide was applied. By spring, the louse population was obviously rebuilding. In late summer all cattle were treated for grubs/lice with a pour-on. They were re-treated for lice in January, and by April there was again some evidence of lice working. Pour-on treatment for grubs/lice the following August was followed with a spraying for flies/lice 18 days later. The cattle were not treated for lice during the following winter and no symptoms of lousiness appeared. This repeat-treatment method has been continued.

KEY TO SUCCESS

Our experience with comprehensive demonstrations reveals personnel as the key. The demonstration can be successful when personnel involved are interested, cooperative, and enthusiastic about the project. These personnel include: interdisciplinary team of extension specialists, university administration, local county agent and practicing veterinarians, and local and state agribusiness representatives.

INFORMATION USED IN EDUCATIONAL PROGRAMS

Results obtained from this demonstration have been used extensively in our overall extension program, including winter meetings and short courses. In the past year, articles concerning various aspects of this program have appeared in Southeast Farm Press, Progressive Farmer, Kentucky Cattleman, Kentucky Farmer, Forage News, Forage Progress, Herd Health Memo, and Livestock Breeders Journal. The Beauchamp-Alexander farm was selected as the site for a field day in 1977 and in 1979 was chosen to host the statewide beef-forage field day. The farm has also been selected for a stop on one of the local tours during the XIV International Grassland Congress in June, 1981.

APPLICATION OF CYTOGENETICS TO PLANT BREEDING

By Wayne W. Hanna

Cytogenetics has been defined as "a field of investigation which developed from the separate sciences of genetics and cytology and is concerned with problems based on the correlation of genetic and cytological features characterizing a particular genetic system under investigation" (43). This definition indicates that cytogenetics involves more than cytology. In fact, I do not believe that there are definite boundries that divide research of cytogeneticists, geneticists, and breeders. There is much overlap and interdisciplinary dependence among areas. What you consider yourself depends on where the most emphasis is placed. All three disciplines are basically concerned with the manipulation and association of genes and chromosomes.

In this discussion, I do not intend to review the literature but to indicate some areas in which cytogenetics has made contributions to plant breeding in forages and to project areas in which progress can be made in the future.

The importance of the application of cytogenetic methods, tools, and findings to breeding programs is recognized by most plant breeders. In the future, it will become increasingly more important for cytogeneticists and plant breeders to coordinate their objectives and findings in order to maximize production from our cultivated plants.

Cytogenetics has and will continue to make direct contributions in the areas of ploidy, sterility, chromosome behavior and stability, inter- and intra-specific and intergeneric hybridization, genetic and linkage analyses, gene transfer, and apomixis. It will aid in producing new genetic systems and mutations, in bypassing or eliminating barriers to plant improvement, in "tapping" the large storage of germplasm in our world gene pools, and in understanding, enhancing, and fixing hybrid vigor.

APOMIXIS

Apomixis (seed production without fertilization of the egg or vegetative reproduction through the seed) is present in many of the forage species. It was once considered an evolutionary "dead end," but now its potential in plant breeding is being recognized (4, 6, 14, 49) as information on its nature, inheritance, and manipulation is accumulated. The most obvious advantage of obligate apomixis is that it will fix heterosis in a particular genotype even though it reproduced by seeds. Apomictic cultivars would not require isolation for seed production and would allow greater potential in developing superior gene combinations. However, for apomixis to be used in plant breeding, cross-compatible sexual and apomictic plants must be available. If not available, a search for them within the species or in a related species is needed (29, 34, 35, 36, 37, 50). The isolation of a sexual plant in buffelgrass has made possible the release of three improved obligate apomictic hybrids in this species (3, 5).

Apomixis is already making a contribution to improved forage types and will become increasingly important as a plant-breeding tool as more is learned about its nature and manipulation. Much needs to be learned about the use of facultative apomixis, the transfer of alien chromosomes or chromosome segments with apomictic genes and methods of turning apomixis "off and on" with chemicals. Apomixis provides a challenge and opportunity to plant scientists in the future.

WIDE CROSSES

Wide hybridization offers exciting potential (22) in plant improvement in that the hybrids can be 1) directly used for forage (32); 2) used after backcrossing and/or selection (8, 9, 10, 20, 38); 3) used for transferring germplasm between species through backcrossing and selection; 4) used to reverse gene flow; 5) used to bridge species through ploidy levels (1, 2, 21, 24, 26, 42); and 6) used to determine species relationships (11, 12). Interspecific and intergeneric hybridization has recently resulted in the release of germplasm (27, 47, 48) and a new cultivar (7). Most scientists involved in plant improvement recognize the wealth of germplasm (such as pest resistance and drought tolerance) in the wild species. The use of cytogenetic technique and principles will be important in order to utilize that germplasm. The greatest challenges in this area in the future will be overcoming species crossing barriers and the transfer of alien germplasm.

CHROMOSOME NUMBER, CHROMOSOME BEHAVIOR, AND FERTILITY

Probably the greatest contribution of cytogenetics to plant breeding has been in the areas of determining chromosome numbers, ploidy, chromosome behavior, and fertility and compatibility relationships (19, 23, 25, 28, 31, 44, 45, 46). These are basic characteristics that are essential in every breeding program. They will continue to be important as we explore the germplasm in the world collections and wild species. Just recently (unpublished) we examined meiosis in plants of pearl millet from one of the most popular varieties in Senegal and found that there was a reciprocal translocation (introduced from a grassy cultivar) in the population. This translocation could reduce grain production by 50%. A plan of action for eliminating the sterility problem becomes more effective when the cause is identified.

PLOIDY

There is much to learn about the effects of ploidy on gene expression. It is generally accepted that increased ploidy results in increased size of plant parts. However, recently we found that in a number of isogenic triploid and hexaploid pearl millet x napiergrass hybrids, phenotypic expression depended both on ploidy and the genotype (unpublished).

Most apomicts are polyploid; however, an artificially induced tetraploid of a sexual diploid usually remains sexual (14). Recently it was shown that the colchicine-induced tetraploid and hexaploid forms of sexual *Paspalum hexastachyum* became facultative apomicts (41). This may not have been detected without cytogenetic techniques.

Interest in haploids has increased since the advent of anther culture techniques. Although the haploids themselves may not be of agronomic value,

they have potential in plant improvement and in developing breeding techniques (40). Haploids could be valuable in establishing genome relationships, especially in polyploid species in which the chromosomes are not morphologically distinguishable. Doubling the chromosome number of haploids from a heterozygous apomictic plant would be a quick way to produce true-breeding sexual plants. Varieties developed by the doubled haploid technique are being evaluated in a number of crops and some, such as Mingo barley, are being released.

The manipulation of chromosome levels and numbers has been and will continue to be important in the utilization of germplasm both within and between species.

MUTAGENS

The use of radiation and chemical mutagens is one way to speed up change that would occur in nature over a much longer period of time. Radiation breeding has been successful for improving pest resistance (15), winterhardiness (13), quality (33, 39), drought tolerance (30) and cytoplasmic male sterility (15). It has been useful for studying effects of radiation on combining ability (18) and yield and quality of forage (17). Success can be expected with radiation breeding only after adequate planning and evaluation have taken place and large numbers of plants are evaluated.

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FIELD AND GREENHOUSE INNOVATIONS FOR THE FORAGE PLANT BREEDER

By K. H. Quesenberry

Most forage plant breeders, regardless of the species they are working with, spend a large portion of their research time in three general areas: (1) developing and evaluating greenhouse techniques for rapidly screening large quantities of germplasm or making controlled pollinations and other types of genetic manipulations in the greenhouse; (2) germinating, planting, and transplanting genetic populations to field nurseries; and (3) sampling, harvesting, weighing, and processing samples from field nurseries. Most breeders decide within a short time those techniques which are useful and efficient. However, another breeder at a different location may devise a more efficient way to accomplish a similar task but several years may pass before these techniques become known to a majority of the forage breeders. Techniques which apply for one crop may need to be modified to be used successfully with other crops.

The objectives of this paper are to present some techniques which have been suggested by various forage plant breeders as useful in their program and to attempt to point out the advantages and disadvantages of some of these procedures. Those techniques which have been published are referenced and individuals who have supplied personal communication are acknowledged at the end of the paper. For convenience, the discussion will be divided into greenhouse techniques, techniques for planting and transplanting, and field sampling techniques.

GREENHOUSE TECHNIQUES

Many screening procedures for forages in the greenhouse involve growing a segregating population in metal or wooden flats. A procedure for rapid planting of spaced seed in such flats involves the use of a vacuum seed planter. The design of such a planter varies with the screening procedure but the basic principle encompasses drilling holes slightly smaller than the size of the seed to be planted into a hollow enclosure to which a vacuum can be applied. The planter head may be as large as an entire flat or as small as one row across the narrow dimension of the flat. Devices such as a length of copper pipe with both ends enclosed and a "T" handle attached have been used to plant single rows. A narrow tray may be used to hold the seed for vacuuming onto the head. Two sheets of plexiglass sealed around the edge with a small space between to form the vacuum chamber have also been used. Here a rim around three sides holds the seed as the vacuum is applied. A head such as this was used by Dr. Jim Elgin (personal communication) in screening large populations of alfalfa (*Medicago sativa* L.) for anthracnose resistance. We have used a two-row seeding head constructed from box aluminum at the University of Florida to screen tropical forage legumes in flats for tolerance to low soil pH. This device permits rapid planting of spaced seeds in rows. Dirty or chafey seed may plug the holes. Burton (1965) reported on a different type flat planter which he used successfully for bahiagrass (*Paspalum notatum* Flugge).

One method of breeding manipulation which has been used successfully in forage legumes to overcome self-incompatibility is heat treatment of the inflorescence prior to anthesis (Hair et al., 1978; Kendall and Taylor, 1969). These methods increase psuedo-self compatibility in the clovers from less than 1% to 10-15%. This ability to obtain self progeny opens new breeding techniques to the forage breeder.

Various types of pollination bags have been used in making crosses of forage grasses. Hovin (personal communication) reports "good success in bagging reed canarygrass (Phalaris arundinacea L.) panicles in dialysis tubing." The tubing permits moisture to pass through and allows good seed retention from mutual pollinations in reed canarygrass. Other types of pollination in bags (mostly used in the field) include those typically used for shoot bags in corn, terylene bags for some tropical grasses, and insecticide-treated kraft bags for millet.

Both day length and quality of incandescent light have been used by forage breeders to increase efficiency in their programs. Some breeders are successfully shortening the time required to flowering by growing plants in small 10-cm pots under short days at elevated temperatures. Hanna and Burton (personal communication) have grown pearl millet [Pennisetum americanum (L.) Leeke] to anthesis in 45-50 days under these conditions in a greenhouse. By scheduling plantings for short winter days, they have succeeded in growing four generations of pearl millet per year. Elgin (1977) has shown that the quality of available light can increase greenhouse total seed yield in alfalfa by 400% over incandescent light. He found that the best light source was high-pressure sodium.

An area of considerable interest to many plant breeders is the ability to manipulate ploidy levels in breeding populations. Taylor et al. (1976) at these meetings summarized the success of colchicine vs. nitrous oxide (N_2O) and concluded that nitrous oxide gave a much higher percentage of tetraploid plants in Trifolium. The technique he used is applicable only if viable seed are produced. Buckner (personal communication) reports that with sterile interspecific and intergeneric hybrids, for which nitrous oxide is not suitable, good success has been obtained in doubling chromosome number with colchicine. His technique involves digging plants from the field after they have undergone winter hardening, removing all dead material, and repotting six to eight tillers per pot. Plants are then allowed to grow about 10 days, after which time the soil is again removed from the roots and the plant materials placed in a 0.2% aqueous solution of colchicine for 22 hours. The plants are then removed from the colchicine solution, rinsed in slow running tap water for approximately 2 hours, repotted, and placed under an 18-hour photoperiod.

One additional technique that has been useful in maintaining virus-free parent clones of some synthetic varieties is the use of tissue culture of meristems to free plants from systemic viruses. Both Gibson and co-workers (1975) and Phillips and Collins (1979) have used this technique successfully (Trifolium pratense L.) from various systemic viruses. This technique permits long-term maintenance of superior clones in the greenhouse or field without loss to virus contamination.

PLANTING AND TRANSPLANTING TECHNIQUES

Many different techniques have been developed for planting and transplanting plants and seeds to field nurseries. Various types of flats and other

containers have been developed for growing plants in the greenhouse prior to transplanting to the field. Among these are Expandapots[1], manufactured in Japan and distributed by United Asia Trading Co., Carson, California. Sleper (personal communication) reports excellent success using these type pots to grow seedling transplants of tall fescue (Festuca arundinacea Schred.) on greenhouse benches. In recent years, many forage grass breeders have used Conetainers (Ray Leach, Conetainers, Cranby, Oregon) for grass transplants. The advantages of these containers is that the roots tend to grow straight down the sidewall and no curling of the roots in the bottom of the flats occurs. Since the Conetainers are held off of the greenhouse bench by a rack, air pruning of the roots at the bottom also occurs. Some difficulty in removing young legume transplants from Conetainers has been experienced. Other researchers have reported good success in using Todd Planter Flats (Speedling Manufacturing, Inc., Sun City, Florida) molded from styrofoam with inverted pyramid-shaped cells. Cell size and depths vary from 1/2" squares by 1" deep to 4" square by 4" deep. The cell design forces plant roots to grow down and also does not permit the twisting of plant roots in the bottom of typical square-type cells. A disadvantage of these and the Conetainers is that they do not stack together and thus require a large storage area when not in use. Many researchers still successfully use peat pots or Jiffy strips for seedling maintenance until time for transplant.

Burton (1976) described a simple hand transplanter for planting grass seedlings from 5-cm clay pots into the field. He says that growing plants in these small pots insures uniformly sized plants and the transplanter assures uniform planting. In an effort to further shorten the time per cycle of selection Burton used complete methyl bromide fumigation of most spaced planted bahiagrass nurseries. Although this process is expensive he says that labor saved in weed control and the additional uniformity of plants justifies the cost. The combination of these simple innovations has allowed him to reduce, from 2 to 1, the number of years per cycle of restricted recurrent phenotypic selection in bahiagrass.

Some specialized types of propagation houses have been successfully used by forage breeders. Taylor (personal communication) has used a double walled plastic quonset hut type house for winter propagation of red clover cuttings. He had few problems with cold temperatures and excellent success in rooting cuttings. Buckner (personal communication) uses a lathe house to start tall fescue transplants in July and August for fall planting. This arrangement provides enough shade during the late summer months for good transplant development.

Engelke et al. (1978) have described a modified mechanical transplanter which allows for planting spaced plants in a checked design. The principal innovation on this planter is the addition of a set of guide rollers for a check wire with knots which trip the transplanter water supply each time a plant should be set. The advantage of this unit, as reported by the authors, is the ability to establish nurseries in a uniform grid pattern using a mechanical transplanter, thus allowing for cross cultivation for weed control in nursery maintenance. They reported this system reduces the hours of hand cultivation by about 60% and expedites establishment of nurseries. Many researchers who are currently using tobacco transplanters for planting transplants could modify their trip mechanism by using this check head assembly to plant spaced plants.

Barker et al. (1976) reported on a cone-type seeder for planting small-seeded forages. The advantages of their seeder, as described by the authors, are an Øyjord (1963) cone with Zero-max variable speed drive and from one to seven double disc openers with depth bands. The spinner portion of the cone is powered by an electric motor. Engelke (personal communication) reports planting seed as small as alkali sacaton [Sporobolus airoides (Torr.) Torr.] with an Øyjord cone. At Florida we have evaluated a different type of cone seeder and find that this unit is not acceptable for planting small-seeded forages. The small seeds tend to become lodged under the cone and cause skips. Another method for planting seeds at a uniform spacing involves the use of tape seeding. Small forage legume seed are placed on a geletin based tape (Grow Craft International, Salinas, California) at any spacing. These tapes containing the seeds can be planted with a modified conventional placer. I have used this method to obtain space plants of red clover in a selection nursery in Gainesville, Florida. Prine (personal communication) has successfully used this method to establish space plants of ryegrass (Loluim multiflorum Lom.) in his program which led to the release of 'Florida' reseeding ryegrass. The advantages of this method are very uniform spacing and planting depth. Disadvantages include cost and at least 1 1/2 - 2 lbs of seed needed to operate the tape placement device.

FIELD SAMPLING TECHNIQUES

Improvements in field sampling and harvesting techniques probably can save more labor for the forage plant breeder than any other area. However, what works for one individual with a particular crop may not work successfully with another researcher. The simplest approach that most researchers have used for harvesting forage plots is some modification of a sickle-bar mower. This may be a short mower attached to a tractor or a sickle-bar on a small gasoline powered tractor such as a Gravely tractor, Simplicity tractor, or Jari. After the forage is mowed down it is generally raked up and bagged. Burton (personal communication) has modified a sickle-bar mower by placing a catch pan directly behind the bar to catch the forage and then dump it into a sample bag. He feels that for bahiagrass harvest this approach is most efficient. Other researchers have used a modified rotary lawnmower with a small catch bag on the side to catch the samples. The disadvantage of this procedure is that the samples are not acceptable for botanical composition separation after passing through the rotary mower and on sandy soils this type mower may pick up excess sand with the sample.

In recent years, several types of flail harvesters have been designed. One such harvester, used by many forage researchers, is the Carter harvester (Carter Manufacturing Company). This machine (Buker, 1967) utilizes a self-propelled flail-type harvesting system and blows the harvested forage through a shoot into a catch bag at the rear of the harvester. Buluch et al. (1975) modified this to use a load cell catch and weight system behind this type harvester. The advantages of such a harvester include its ability to chop tall forages, rapid sample harvest, and relative ease of operation. The disadvantages of this and other flail-type harvesters are: excess soil may be blown into the sample bag with the forage; the size of the machine requires large alleys for maneuvering; and an experienced operator is needed to handle the machine. Other researchers have adapted a flail-type harvester to the front of small riding lawnmower tractors (R. R. Smith personal communication)

with success. For harvesting millet Burton (personal communication) uses a standard one-row forage chopper with a catch hopper mounted behind a two-wheel platform which also has a scale for weighing the sample and a working platform for bagging a sub-sample if needed. This small trailer is pulled behind the typical forage harvester and greatly speeds up the operation of harvesting pearl millet forage.

One of the major time-consuming steps in sampling field plots is accurately weighing field samples. Usually with larger forages, the entire plot sample is weighed for fresh weight and a sub-sample is taken to determine moisture content. Engelke and Campbell (1978) reported on the use of a portable electronic field scale that "reduces labor and increases efficiency and precision in collecting field data." The scale consists of a low-profile platform transducer with a 1200-cm^3 surface area and a digital weight recorder. The key element in the system is the digital weight recorder which supplies the necessary power and microprocessor controls The microprocessor with a 16-button keyboard is used to provide programmed sequences for storing and recalling tare weights and for displaying and recording net weights. It was also used to develop an integration system load measurement which allows field weighing under very windy conditions. The advantages of this system are its usefulness under windy conditions, labor reduction, and less chance of data error in transfer as all data can be recorded on magnetic as well as paper tape for rapid transfer.

The simple disc meter (Quesenberry and Ocumpaugh, 1978) is a tool for estimating plot yield that we have found quite useful. The devise involves estimating yield as a function of compressed forage height under a 1/2-meter square disc. In one experiment of Hemarthria genotypes, the regression coefficients were not changed significantly by a range in plant heights from 10 cm to 40 cm. R^2 values were 0.73 to 0.88.

The ideas and devices presented in this paper will hopefully stimulate all forage breeders to critically examine their programs for ways to increase efficiency. One way for a breeder to improve proficiency and productivity is to decrease the time required per cycle or per generation of selection. If we as plant breeders are to continue to meet the demands of a growing world food shortage we must continue to develop new ideas and techniques to improve our efficiency.

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[1]Mention of a Trade name does not constitute a recommendation to the exclusion of others or a warranty by the author or the University of Florida. These are presented only as sources of information to the reader.

FORAGE SEED PRODUCTION IN THE SOUTH?

By M. C. Engelke and J. B. Moutray

The most common types of forage available to the American farmer until the mid-1940's were local ecotypes. Seed was harvested from pastures and fields on a periodic basis depending on the hay or feed supply. This incidental crop of seed served as a means of perpetuating numerous "local varieties" for additional plantings on home and neighboring farms. Seed yields, following a good hay crop, may have averaged 90-100 pounds per acre for alfalfa or as high as 200 pounds per acre for forage grasses. These seed yields were generally sufficient to meet local demands.

Since the mid-1940's, however, improved varieties of nearly all forage grasses and legumes have become available and well accepted by the farm community. These new varieties have better adaptability, winter hardiness, and pest resistance, along with higher forage quality and superior forage production. Evolving with these new varieties came the foundation seed stock programs and seed certification agencies. These agencies and programs provided the rules, regulations, and direction needed to maintain the genetic integrity of the new varieties and to ensure the availability of high-quality seed stocks.

Having coupled these regulations with the increased demand for seed supplies, we were provided sufficient incentive to develop seed production per se as a primary industry. And from such emerged the seed production specialist, with his unique set of cultural and management practices--practices which included moving and developing this industry in an environment more conducive to maximizing production of high-quality seed.

In the next few minutes, I'll discuss several factors which influence the seed production industry and hopefully provide an understanding of the risk involved in seed production as it would relate to the forage-producing states.

Climate undoubtedly plays an extremely important role in the successful production of high-quality seed. Adequate moisture is essential during the vegetative and floral initiation period; however, as seed is set and approaches maturity, additional rains become a deterrent. Additional moisture at this time can stimulate development of secondary tillers. Anthesis and seed set in these late tillers will occur at the time of full maturity in the primary tillers. This discrepancy in crop maturity causes an increase in both time and expense for harvesting and conditioning, and increases shattering loss, and, of major importance, is the compromise suffered in seed quality. Secondly, precipitation occurring at the time of harvest will cause considerable lodging, shattering, and general decrease of seed quality. The resulting seed crop may not be worth the expense of harvest, or at best, will be of low quality, low germination, and lightweight seed. Additionally, those seed stocks which are salvaged will generally require additional mechanical drying prior to cleaning and conditioning.

Untimely rains can also result in total crop loss by causing seed sprouting in the heads prior to harvest. Summer rains occurring in eastern Washington, Oregon, and Idaho these past 3 years resulted in a 40% crop loss in

alfalfa. Losses such as these are more commonplace in the Middle Western, Eastern, and Southern States. In California, Oregon, Idaho, and Washington, where 83% of all legume seed production occurs, most moisture for seed production is provided by controlled irrigation. The moisture requirement for grass seed production in the Willamette Valley of Oregon, in contrast, is adequately provided by its typical winter rainfall pattern (similar to the Mediterranean region). There, little or no precipitation is received during the critical seed set and harvest seasons, resulting in high-quality seed production. This type of precipitation pattern contrasts with that occurring in the Central Midwest, East and South where heaviest rains occur in May and September, with frequent thunderstorms and high winds commonplace throughout the summer.

Cultural practices were developed by the seed production specialist with the primary objective of maximizing yields of high-quality seeds.

Controlled irrigation permits close management for maximum plant development and seed yields. Controlling moisture and manipulating plant stress can also induce prolific flowering and more uniform seed set. Timely maturation facilitates the harvest and processing, and results in better yields of a higher quality product.

Seed production is also favored by lower plant populations, which allow for maximum plant development and seed production. Typically, seeding rates averaging 10% to 20% of the recommended forage production rates are used in seeding both grasses and legumes in rows. Seed production research has shown that individual plant development and seed yields are enhanced in row plantings where competition for moisture, nutrients, and light is minimized. In addition, rows aid in mechanical and chemical weed control practices and greatly facilitate flood or rill irrigation.

Field burning has been one of the most controversial cultural practices utilized by the agricultural industry. In spite of its ecological disadvantages, field burning has been utilized effectively in the Pacific Northwest to: 1) provide effective field sanitation for control of seedling, weeds, and disease inoculum, 2) eliminate straw and other accumulated plant debris, and 3) induce thermal shock in the crowns of numerous perennial grasses, which enhances tillering and increases seed yield potential the following year. An effective field burn requires generally dry field conditions. Temperatures must be hot enough to give a thorough sanitizing burn, yet quick enough so as not to injure the mother plant. In general, the unpredictable climatic conditions of the Central and Eastern States would prohibit field burning as a common reliable practice. Pressures exerted by the environmentalists the past 10 years have caused a considerable reduction in burned acreage. In 1970, nearly a million acres were burned annually in Oregon, whereas in 1979, laws imposed by the Environmental Protection Agency limited burning to 180,000 acres. New practices are presently being researched and utilized eliminating open-field burning. As an example, a significant acreage was burned this past year using propane burners. This process, as you can well imagine, is quite expensive and time consuming, as a double burn is usually required for effective weed and seedling control.

Pollinators are an essential component of the legume seed industry. Previously, natural populations of either the bumblebee (*Bombus* spp.), honeybee (*Apis mellifera* L.), or alkali bee (*Nomia melanderi* Ckll.) provided sufficient pollination. However, as the seed production industry intensified in the past 25 years, greater demands for reliable populations of pollinators have prompted the use of domesticated bees and, in numerous cases, a complete pollinator

service. The most frequently employed species include the honeybee, the alkali bee, and in recent years, the leafcutter bee (Megachile rotundata Lf.). The bumblebee has been too difficult to domesticate. In domesticating these bees, special consideration must be given to their biological functions, life cycles, and other needs and problems as well. The most serious problems are diseases and insects which directly affect the bee. As many as 30 different pests have been identified as predators to the leafcutter bee alone. When left uncontrolled, they greatly influence the stability and health of the pollinator. These include a sapygid wasp (Sapyge pumile), a minute chalcid (Tetrasticus sp.), and an imported chalcid (Monodontomerus obscurus) as parasites and the carpet beetle (Trogoderma glabrum) and checkered flower beetle (Trichodes ornatus), which are examples of nest destroyers. In addition, diseases of the hive are becoming more commonplace and require special management to suppress losses. Chalkbrood is the most common with the leafcutter bee.

Diseases and insect pests of the plant must also be considered, as the general health of the plant will dictate potential seed yield. Disease and insect problems associated with seed production are often not found in forage production fields. Insect populations and disease inoculum do not have the opportunity to build up as rapidly, due to frequent defoliation of the plant.

Integrated pest management programs have evolved to aid in control of beneficial and harmful insects affecting the pollinators and plant populations. An effective IPM program will employ trained field scouts during the peak insect season. These scouts will make several hundred sweeps and insect counts daily. The population levels of both beneficial and harmful insects are closely monitored. Data collected are used in making recommendations in the most effective means of control.

Where the leafcutter bee is used, short residual insecticides are aerially applied at night when the bees are dormant. Residual time of these chemicals may be measured in hours and minutes, and not in months or days.

Other problems of a lesser nature exist with the pollinators, as well. For example, this past year, with frequent thunderstorms and heavy winds, very high losses of bee populations were reported. In a number of cases, the bees were simply blown away by strong winds.

Numerous breeding programs in both grasses and legumes are directing their attention to problems unique to the seed production industry. Unfortunately, progress in plant breeding is relatively slow and other techniques and procedures are needed to aid us in our ever-changing environment as well.

Advances have been made in developing new varieties with specific types of resistance. With the present system of forage and seed production, it has been necessary to develop strains with insect and disease resistance for both regions. The grasses are particularly vulnerable to the numerous species and races of rust, both in the Pacific Northwest where seed yields can be drastically reduced, and in the East, where forage yield and quality are impaired.

More sophisticated technology has evolved in the harvesting and conditioning of these high-yielding seed crops. Larger and more reliable equipment has become available to ensure more timely harvest. Popular use of chemical desiccants, such as paraquat, diaquat, and sodium chlorate, have enhanced seed quality and uniformity of seed maturity, and facilitated harvest by reducing the amount of material passing through the combines. Windrowing the seed crop just prior to its reaching maturity also aids harvest of more uniform seed quality with reduced losses to shattering.

Particular problems associated with having the seed industry in the West

have become more important in the past 5 years. Transportation costs have skyrocketed in the past 6-8 years, with all probability of doubling within the next 5 years. At today's rates, transportation alone can account for as much as 30% of the retail price of seed. These increased costs have also reduced the number of truckers available, resulting in untimely delays and often reduced seed supplies. If seed production occurred closer to the marketplace, these problems would be significantly diminished.

Presently, economics would not support the development of a major seed industry in the South. Seed crops are too unreliable, isolation of certifiable varieties would be difficult, and the quality of seed generally produced would not be acceptable to our modern-day farmer.

In conclusion, we must realize that even though some seed production can and will occur in the primary region of adaptation, the quality of seed--germinability and purity--and the quantity of seed will be compromised. For seed production of these small-seed grasses and legumes to be successful, the producer has to have some assurance that he'll receive a return on his investment comparable to alternate farming practices and land use.

ENERGY, ECONOMICS, AND THE PRODUCTION OF NITROGEN FERTILIZERS

Some Insights and Implications

By Donald R. Waggoner, Robert G. Lee, and Thomas H. Foster

Any logical examination of the impact of increasing energy costs and/or decreasing energy availabilities on the fertilizer industry quickly leads to nitrogen and ammonia. First, in terms of relative importance as a macronutrient, nitrogen is dominant. In 1979, nitrogen accounted for 48 percent of the total plant nutrients consumed in the United States and, as shown in Figure 1, it is estimated that this will increase to 50 percent by 1985 (1). Secondly, the production of nitrogen, relative to phosphate and potash, is energy intensive. One estimate places the embodied Btu value of a pound of nitrogen at 28,000 as compared to 5,000 and 4,000 Btu per pound of P_2O_5 and K_2O, respectively (2). And, finally, anhydrous ammonia dominates the nitrogen fertilizer material picture--not only because ammonia is the base material for almost all nitrogen fertilizers (Figure 2) but also because it is the leading direct application material. Of the 10.6 million short tons of nitrogen consumed in the U.S. in 1979, 80 percent (8.08 million tons) was direct application materials (Figure 3), and anhydrous ammonia accounted for roughly 50 percent (4 million tons) of the direct application nitrogen, Figure 4 (1).

Just as rapidly as one is led to nitrogen and ammonia in examining the economic aspects of fertilizer and energy interaction, so is one led to the feedstock decision in a closer look at the economics of ammonia production. Until the early 60's the ammonia industry was based on production units, using a reciprocating compressor, with a maximum design capacity of 350 tons per day. The size of the production train was limited by heat exchange and compression equipment sizes. Increased capacity was acquired by simply multiplying the number of production trains. Technological improvements in ammonia processes and equipment, especially use of centrifugal compressors, recovery of waste heat, increases in reforming pressure, reduction in ammonia synthesis pressure, and virtual elimination of electrical power consumption significantly increased the size of economically feasible single trains, and form the basis of today's industry. Plants built since 1963 have incorporated these improvements and have integrated the energy balance across the steps of gas generation, purification, and synthesis. The net effect of these developments has been to increase plant size and to favor either natural gas or naphtha as a feedstock (3,6).

Therein lies the current dilemma. On one hand engineering progress has made natural gas and naphtha the feedstocks of choice; on the other hand, natural gas and naphtha, as with all fossil fuels, have experienced substantial increases in market prices in reaction to a host of economic variables and political actions. Increased costs coupled with decreasing availability of these feedstocks have stimulated substantial interest in increasing the efficiency and utilization of ammonia plants. Although marginal improvements can be made, significant new "breakthroughs" in technology are not expected. What, then, can be expected?

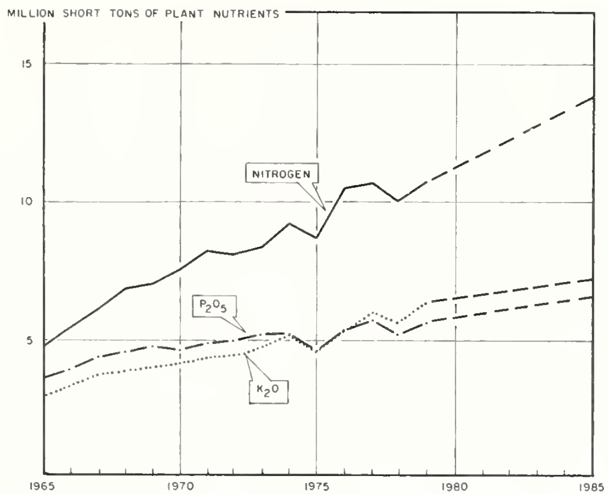

Figure 1.--Plant nutrient consumption in the United States. Source: Ref. 1, p. 7.

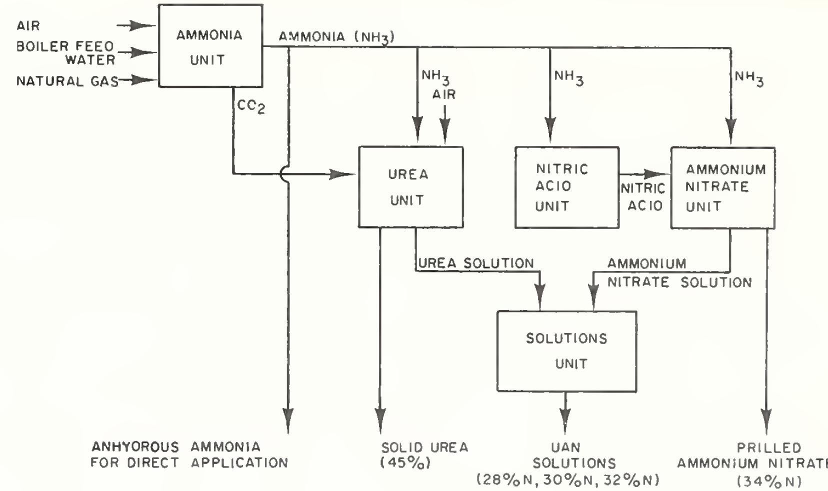

Figure 2.--Schematic diagram--nitrogen fertilizer production.

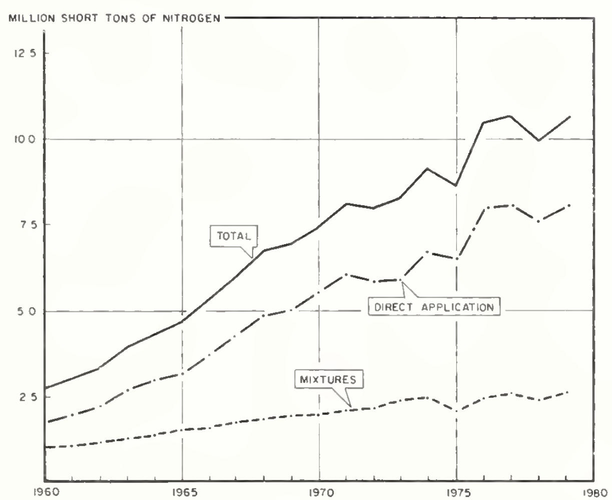

Figure 3.--Consumption of nitrogen fertilizer in the United States. Source: Ref. 1, p.11.

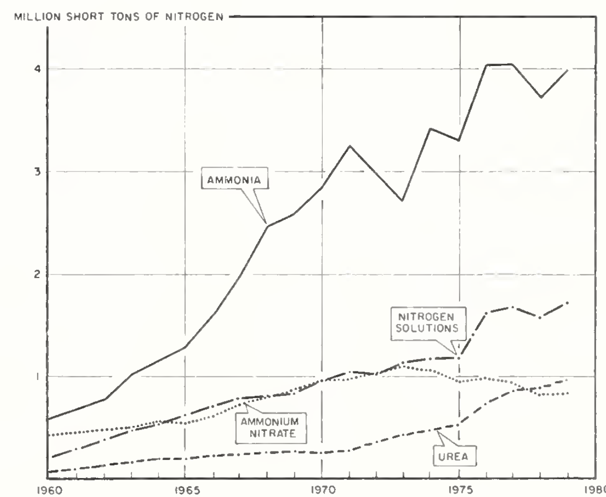

Figure 4.--Consumption of nitrogen fertilizer materials in the United States. Source: Ref. 1, p. 12.

To gain some insight into this question of energy economics and nitrogen fertilizer interaction, a closer look at the economics of ammonia production is in order. Since ammonia is the base for nearly all nitrogen fertilizer, it can serve as the least common denominator and can narrow our focus to manageable proportions. In order to accomplish this, estimates of the cost of producing ammonia in 400, 600, and 1,000 ton per day capacity (TPD) plants from natural gas in 1973 will be made. Using this base, the impact of increasing natural gas prices on the cost of producing ammonia in a 1973-built 1,000 TPD plant will then be estimated for the period 1973 through 1979. Additionally, the impact of the increasing opportunity cost of 1973 invested capital will be estimated for a 1,000 TPD plant in 1979. Finally, to simulate the effects of new gas contracts with their attendant higher prices and to reflect capital investment escalations, we will estimate the cost of producing ammonia in a 1,000 TPD natural gas-based plant coming on stream in 1980. For comparative purposes an estimate of ammonia production in a coal-based facility is then developed.

PRODUCTION COST ESTIMATES

In an attempt to narrow the perspective, all cost estimates presented are based on what may be termed "full economic costs." That is, all specified resources and variable inputs are valued at their assumed opportunity cost. This reflects the cost associated with keeping the resources employed in that use. Use of this concept makes the simplifying, but realistic, assumption that changes in resource compensation among industries and sectors of the economy will be relative. Thus, the focus of the estimates is the cost to society as estimated at the opportunity costs of resource, and as reflected in the marketplace. The estimates do not reflect corporate financial management consideration such as profit and loss, return to equity, capital budgeting, return on investment, etc. In that sense they are partial; but for the purposes of this paper in examining the impact of increasing feedstock prices on nitrogen fertilizer production costs, the estimates are sufficient.

The 1973 Situation

Estimates of the investment requirements and production costs associated with natural gas-based ammonia plants of 400, 600, and 1,000 TPD capacities beginning operation in 1973 are summarized in Table 1 (4,5). The 400 TPD plant is assumed to an electric motor driven compressor plant. The 600 and 1,000 TPD plants are assumed to be more modern, using steam-driven centrifugal compressors. All costs are based on operation at design capacity levels and the assumptions specified in Appendix Table I (5). Total depreciable capital investment as used does not include working capital or land costs.

A cursory examination of the resulting cost estimates for ammonia production in 1973 reveals two important facts. First, though there are economics associated with size of plant, the <u>relative</u> impact of energy on per ton costs is of the same magnitude for the plants analyzed. Full economic costs were estimated to be \$54.53, \$44.39, and \$40.23 per ton for 400, 600, and 1,000 TPD plants, respectively, with energy cost accounting for roughly 44 to 48 percent of full economic cost (\$19.35 to \$25.29 per ton). In short, this supports the earlier statement on the energy intensiveness of nitrogen production and implies that one cannot run away from the problem by building a larger plant. The feedstock and energy-to-product ratios for nitrogen are relatively fixed. Secondly,

Table 1: Estimated Full Economic Costs for Ammonia Plants Beginning Operation in Mid-1973. Natural Gas Reforming (4,5)

	Plant Capacity (Tons/Day)					
	400		600		1,000	
	mil $	Cost/Ton	mil $	Cost/Ton	mil $	Cost/Ton
Depreciable Investment	19.5	48,700	26.0	43,300	36.4	36,400
	Units/Ton	$/Ton	Units/Ton	$/Ton	Units/Ton	$/Ton
1. Energy Costs						
Natural gas						
a. Feedstock-MCF @ $.50	23.0	11.50	21.0	10.50	21.0	10.50
b. Fuel-MCF @ $.50	15.0	7.50	17.0	8.50	17.0	8.50
Total	38.0	19.00	38.0	19.00	38.0	19.00
Electricity-kWh @ $.01	624.0	6.24	35.0	0.35	35.0	0.35
Total Energy	-----	25.24	----	19.35	----	19.35
2. Other Variable Costs (cooling water, boiler feed water, cat. & chem. labor)		2.75		2.97		2.65
3. Fixed Cost						
a. Maintenance, taxes, insurance & overhead		11.24		8.47		6.80
b. Depreciation		9.56		8.50		7.14
c. Interest		5.74		5.10		4.29
Total Fixed Cost		26.54		22.07		18.23
4. Full Economic Costs		54.53		44.39		40.23
5. Energy Costs As Percent of (4)		46.20		43.50		48.10
6. Depreciation & Interest As Percent of (4)		28.00		30.60		28.40

the plants are, to a degree, capital intensive with approximately 30 percent of full economic costs accountable as interest and depreciation. If these resources are to remain in nitrogen production over the long run, they must receive at least what they can earn in their next best alternative.

Taking only these three items--energy, interest, and depreciation--we can account for roughly 75 percent of the cost of producing a ton of ammonia in 1973. From this perspective it is apparent that the supply cost of ammonia is extremely sensitive to the cost of these three items. To examine this sensitivity let us allow these items to vary in price (cost) one at a time in order to try and trace these effects.

Impact of 1973-1980 Developments

The cost of natural gas to ammonia producers has risen steadily over the past decade. A TFI report (7) indicates that the natural gas costs have risen roughly 400% from 1973 to 1980 (Table 2). Assuming no price changes other than natural gas, what effect would this have on production costs? Using the base production cost estimates presented in Table 1 and the natural gas prices paid by year from Table 2, the impact of escalating gas prices was estimated. The results are summarized in Table 3.

The results are as expected. Based on energy costs alone each one percent increase in energy costs will result in an increase of approximately one-half of one percent in full economic costs (Tables 1 and 3). And equally important, as energy costs escalate they account for an increasingly larger share thereby increasing the sensitivity of production costs to happenings in the energy market.

A good portion of the natural gas used in 1979-80 is priced according to old contracts. A reasonable figure for new 1980 gas contracts in $2.25 MCF as compared to those previously reported in Table 2. Likewise, it is unrealistic to estimate 1980 production costs on a 1973 interest rate of 8 percent. Taking the 1979 full economic cost of $76.71 per ton of ammonia for a 1,000 TPD plant and incorporating changes to reflect a 15 percent interest rate (to reflect 1980 conditions) and $2.25 per MCF for natural gas (new contract), the result is an increase in cost of $33.76 per ton of ammonia--from $76.71 in 1979 to $110.47 in 1980 (Table 4). In total, this results in an estimated $70.24 increase in cost between 1973 and 1980 (Tables 1, 3 and 4).

While costs of production and market prices of the product are nowhere near synonymous, any evaluation of the market price movements of ammonia over the same period shows the two are closely related and that market prices reflect the underlying economics of production. This is not to say any given ammonia price quote can be judged as "fair," "equitable," or "efficient." But it very strongly implies that the price increases of the 1970's were not "rip-offs" but a rational equation of the true underlying supply and demand forces. A "bottom line" inference is that 1973 ammonia and nitrogen prices are gone--unless 1973 energy, interest, and plant costs return.

The 1980 Situation

In the process of examining the effect of increasing energy and interest costs on ammonia production, capital investments and other costs were held constant at 1973 levels. What happens to this cost picture when all resources and inputs are valued at 1980 prices? Using the same format the costs of producing ammonia in a 1,000 TPD plant coming on-stream in 1980 were estimated.

Table 2: Actual Average Prices Paid for Natural Gas for Use in Ammonia Production, 1970-1979 (7)

Year	Plant Size (Tons/Day) 400	600	1,000
	$/MCF		
1970	0.35	0.27	0.27
1973	0.47	0.39	0.39
1975	0.84	0.64	0.64
1977	1.50	1.51	1.51
1978	1.46	1.46	1.46
1979	1.96	1.46	1.46

Table 4: Estimated Cost Per Ton of Ammonia, 1,000 TPD Ammonia Plant, Natural Gas Reforming, Beginning Operation in Mid-1973, Adjusted to Reflect 1980 Natural Gas Prices and Interest Rates

Item	$/Ton
1979 Full Economic Cost	76.71[1]
Increased Interest @ 15%	3.74
Increased Energy Costs @ 2.25/MCF	30.02
Total	$110.47

[1]From Table 3 (Natural Gas Price = $1.46 per MCF).

Table 3: Estimated Costs Per Ton of Ammonia, 400, 600, and 1,000 TPD Plants, Natural Gas Reforming, Beginning Operation in Mid-1973, Adjusted to Reflect Average Natural Gas Prices[1], 1973-1979

	Plant Size								
	400 TPD			600 TPD			1,000 TPD		
Year	Energy Cost	Other Variable and Fixed Costs	Full Economic Costs	Energy Cost	Other Variable and Fixed Costs	Full Economic Costs	Energy Cost	Other Variable and Fixed Costs	Full Economic Costs
	Dollars								
1973	24.10	29.29	53.39	15.17	25.04	40.21	15.17	20.88	36.05
1975	38.16	29.29	67.45	24.67	25.04	49.71	24.67	20.88	45.55
1977	63.24	29.29	92.53	57.73	25.04	82.77	57.73	20.88	78.61
1978	67.04	29.29	96.33	55.83	25.04	80.87	55.83	20.88	76.71
1979	80.72	29.29	110.01	55.83	25.04	80.87	55.83	20.88	76.71

[1]Based on natural gas prices Table 2.

The results are summarized in Table 5. The supporting assumptions are specified in Appendix Table II (8). In contrast to the $110.47/ton previously reported, a new ammonia plant coming on-stream in 1980 is estimated to have a full economic cost of $134.34/ton. This is roughly a $90 increase per ton in economic costs over 1973, which must be reflected in prices received if the necessary resources are to be attracted into the nitrogen industry and supply current levels of demand.

Ammonia From Coal

The escalation of gas prices and diminishing availability have increased interest in alternative feedstocks. As an outgrowth of this interest, TVA has established an Ammonia From Coal Project at Muscle Shoals, Alabama, for the purpose of evaluating the production of ammonia using coals as a feedstock. The main objective is to provide technical and economic information to the U.S. fertilizer industry for the substitution of coal for natural gas.

Table 6 summarizes the estimated production cost for a 1,000 TPD ammonia plant beginning in mid-1980 using coal as a feestock. The assumptions underlying this estimate are the same as those used for the mid-1980 natural gas plant (Appendix Table II). While both plants are assumed to operate 340 days per year, which is typical for natural-gas-based plants, a coal-based plant would have difficulty attaining this on-stream efficiency. But assuming the TVA project will develop sufficient technology or operating procedures to achieve this level of operating efficiency, what are the comparative economics?

In contrast to the natural-gas-based ammonia cost of $134.34/ton, ammonia from coal is estimated to have a full economic cost of $163.40/ton--a difference of approximately $29/ton. This difference reflects the higher capital requirements ($159 million vs. $82.2 million) of the coal-based facility. However, the coal-based facility has an approximate $24 per ton energy cost advantage (using $27/ton coal).

Is the estimated economic advantage of natural gas over coal as a feedstock for the production of ammonia insurmountable? At first glance a $29/ton advantage appears substantial, but only a 37.3% increase in the natural gas price ($2.25/MCF to $3.09/MCF) would erase the advantage of natural gas, assuming coal prices remain constant. An increase of this magnitude is well within the range of increases experienced in the past decade. Of course, a constant coal price is not a realistic assumption, but it is realistic to assume deregulated natural gas prices will rise at a faster rate than open market coal prices--basic supply and demand estimates, if accurate, dictate that. In addition, ammonia plants located in the consuming regions, and utilizing nearby coal deposits, would enjoy a transportation cost advantage. The value of that advantage is location specific. And, finally, the intangibles such as control of feedstock supply and the freeing of natural gas for other critical uses must be considered. This latter point--changing the source of energy used in ammonia production--may be the most significant. These factors when taken together emphasize the substantial potential benefits to society from ammonia from coal development work. Any, maybe most intriguing of all is that it is not a matter of "re-inventing the wheel" but rather of advancing existing technology. This aspect really improves the benfit to cost ratio.

Table 5: Estimated Full Economic Cost Per Ton of Ammonia, 1,000 TPD Ammonia Plant, Natural Gas Reforming, Beginning Operation in Mid-1980, 340,000 Tons/Year

(Depreciable Investment, $82,200,000[1])

	Units/Ton	$/Ton
1. Energy Costs		
a. Natural gas @ $2.25/MCF	34.5 MCF	77.63
b. Electricity @ 0.027/kWh	3.0 kWh	0.81
Total Energy Costs		78.44
2. Other Variable Costs[2]		3.29
3. Fixed Costs		
a. Maintenance, taxes insurance & overhead		18.36
b. Depreciation		16.12
c. Interest		18.13
Total Fixed Costs		52.61
4. Full Economic Costs		134.34

[1]Calculated from (8), using Chemical Engineering Plant Index of 255.1.

[2]Includes catalysts and chemicals, boiler feedwater, cooling water, and labor.

Table 6: Estimated Full Economic Cost Per Ton of Ammonia, 1,000 TPD Coal-Based Ammonia Plant, Beginning Operation in Mid-1980, 340,000 Tons/Year

(Depreciable Investment, $159,100,000[1])

	Units/Ton	$/Ton
1. Energy Costs		
a. Coal-Feedstock & Fuel @ $27.00/Ton	1.90 Tons	51.30
b. Electricity @ $0.027/kWh	136 kWh	3.67
Total Energy Costs		54.97
2. Other Variable Costs[2]		5.54
3. Fixed Costs		
a. Maintenance, taxes insurance & overhead		36.60
b. Depreciation		31.20
c. Interest		35.09
Total Fixed Costs		102.89
4. Full Economic Costs		163.40

[1]Calculated from (8). Using Chemical Engineering Plant Index of 255.1.

[2]Includes catalysts and chemicals, boiler feed-water cooling water and labor.

SUMMARY AND IMPLICATIONS

Nitrogen dominates the fertilizer nutrient consumption picture and is expected to expand its market share over the 80's as a reflection of its efficiency in food and fiber production. However, nitrogen is energy intensive and sensitive to the vagaries of energy supply and demand. Using ammonia as the least common denominator in nitrogen production, the impact of increasing costs of natural gas, interest, and investment requirements was estimated for the period of 1973 through 1980. It was demonstrated that a one-percent increase in the price paid for natural gas results in roughly a one-half of one percent increase in the estimated cost of producing ammonia and that the cost of supplying ammonia has risen significantly over the past seven years. The prospects for a "roll back" of these cost increases are nil. Higher priced nitrogen is here to stay if it is to be produced over the long run. Research and development of alternative ammonia feedstocks, especially coal, was demonstrated to have a potentially high benefit to cost payoff.

In terms of the implications of these points for forage and grassland researchers and extension workers three points are readily apparent.

1. Research and educational activities to increase the efficiency of nitrogen in forage production and use have high payoff potentials. The key to solving problems stemming from permanently higher nitrogen price lies in increasing the productivity of applied nitrogen thus increasing its value to the forage producer. A host of form, type, placement, timing, response, and harvest questions come to mind here. In this regard, the development of a practical soil test that accurately estimates the nitrogen-supplying capability of a given soil would yield substantial returns to the research investment.

2. Due to forage's intermediate product role, a multi-disciplinary or farming systems approach would be preferred in answering such questions. That is, the "optimum" solutions to such questions cannot be found or communicated in piecemeal fashion. The interrelatedness of forage with livestock production and marketing dictates that the greatest gain will come from simultaneous consideration of all factors to the extent possible.

3. The utilization of biological nitrogen fixation as a source of nitrogen, be it in legume-forage crop production systems or the relatively new work on transferring this ability to grasses and crops, holds substantial promise. A real question that must be answered is: if the nitrogen fixing ability is successfully transferred to non-legume crops what will the plant have to give up in return for the nitrogen gained? Won't it still require those Btu's of energy to produce a pound of N (2)?

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Appendix Table I: Assumptions Used In Developing Cost For Mid-1973 Nitrogen Fertilizer Plants

Location	Gulf Coast.
Operation	340 days per year.
Costs:	
1. Investment	As shown.
2. Depreciation	15 years, straight line, no salvage value.
3. Interest	8 percent on one-half of total plant investment.
4. Taxes & Insurance	2 percent of total plant investment.
5. Maintenance	4 percent of total plant investment (5 percent for reciprocating type).
6. Labor	$4.00 per man-hour.
7. Overhead	100 percent of labor.
8. Utilities	Natural gas, $0.50 per 1,000 cubic feet; electrical power, $0.01 per kilowatt hour; cooling water, $0.02 per 1,000 gallons; boiler feed water makeup, $0.50 per thousand gallons.

Appendix Table II: Assumptions Used In Developing Costs For Mid-1980 Ammonia Plants

Location	U.S. location close to feedstock source.
Operation	340 days per year.
Costs:	
1. Investments	As shown.
2. Depreciation	15 years, straight line, no salvage value.
3. Interest	15 percent on one-half of total plant investment.
4. Taxes & Insurance	2 percent of total plant investment.
5. Maintenance	5 percent of total plant investment.
6. Labor	$8.00 per man-hour.
7. Overhead	100 percent of labor.
8. Utilities	Natural gas, $2.25 per 1,000 cubic feet; electrical power, $.027 per kilowatt hour; cooling water, $0.25 per 1,000 gallons; boiler feed water makeup, $1.00 per 1,000 gallons.

OBSERVATIONS ON THE USE OF MARKERS FOR ESTIMATING VOLUNTARY INTAKE

By Hagen Lippke

Efforts to define mathematical relationships between intake and digestibility of diets selected by grazing cattle and measurable attributes of the sward have required the development of techniques for estimating intake and digestibility. Theoretically, appropriate indigestible markers, one internal and the other external to the forage, can accurately estimate both parameters. In practice, however, deviations due to digestion or absorption of part of the marker and errors in measuring marker concentration frequently produce estimates with large variances. Markers have, nonetheless, provided realistic estimates of both digestibility and intake (Table 1).

Markers are most commonly used in a dilution technique, i.e.,

$$\text{Fecal DM} = \frac{\text{External marker dose}}{\text{External marker concentration in feces}}$$

$$\text{DDM} = \frac{\text{Internal marker concentration in forage}}{\text{Internal marker concentration in feces}}$$

$$\text{DM intake} = \frac{\text{Fecal DM}}{(1 - \text{DDM})}$$

The same calculations can be made on an organic matter basis.

Table 2 provides data regarding the suitability of indigestible neutral detergent fiber (INDF) as an internal marker. Some evidence suggests that recovery from freeze-dried samples is nearer 100%.

The rare-earth elements have been used successfully as external markers (W. C. Ellis, J. H. Matis, and Carlos Lascano, "Quantitating Ruminal Turnover," Fed. Proc. 38:2702, 1979). Their use with the dilution technique requires a constant input, which may pose a technological problem. Ellis and co-workers have developed appropriate procedures and descriptive mathematics for the use of pulse-dosed markers. Table 3 gives a comparison of the dilution and pulse-dose techniques used simultaneously. The higher estimate derived from the pulse-dose is within the range of values from the dilution technique. A rigorous sampling schedule must be observed in order to achieve reliable estimates from the pulse-dose techniques.

Table 1

Estimation of fecal dry matter using erbium and ytterbium markers

Animals	Method	Fecal DM kg	Fecal DM g/kg $BW^{.75}$
Trial 1			
Maxene	Er (pulse)	1.59	21.7
Petula	Yb (dilution)	3.03	33.9
Trial 3			
Maxene	Yb (pulse)	3.48	39.4
Petula	Yb (dilution)	3.72	36.4

Table 2

Recovery of 6-day in vitro residue (INDF) in feces

Forage	n	Recovery	S.E.
		. . . . %	
Sorghum x sudan hay (7)	12	92.2	1.05
Bermudagrass hay (5)	15	95.6	2.92

Table 3

Simultaneous estimates of fecal dry matter

Method	Fecal DM kg	Fecal DM g/kg $BW^{.75}$
Yb (dilution)	3.03	33.9
Er (pulse)	3.33	37.3

A CONTINUOUS INFUSION AND PULSE DOSE MARKER METHOD FOR DETERMINING FECAL OUTPUT

By W. C. Ellis and Hagen Lippke

Fecal output (U_o) can be determined without total fecal collection by the use of an indigestible marker (M) of known daily intake (M_i), together with fecal samples (U), to determine the dilution of M_i by forage intake contributing to U_o. Under steady-state conditions (constant feed input, gastrointestinal fill and fecal output), $U_o = (M_i)$ (M/U), where M/U equals the units of M per unit of U. The common procedure is to give a daily or twice daily dose of marker for 3-5 days to maximum M/U and then collect fecal samples over 3-5 days to obtain the best estimates of mean M/U resulting from M_i during this plateau maximum period. This procedure has the disadvantage of labor required for daily dosing of M which could be reduced by an _in situ_ infusion pump dispensing M_i. A pump system (together with batteries and a reservior of 300 ml 0.7 _M_ CrEDTA) sufficiently small to be incorporated into a 3" diameter x 8" long plexiglass tube and inserted into the rumen cannula has been designed and found satisfactory. Lower variations in M/U were observed by this method than by twice daily dosing of Cr_2O_3. Further improvements are being incorporated into the pump to reduce its size and increase its reliability.

U_o may also be estimated from changes in M/U following a pulse dose of M by $U_o \cong U_f \times kp$, where U_o = fecal output, U_f = fill of undigested matter in the gastrointestinal tract which will appear as U and kp = turnover of U_f. U_f is estimated from the dilution (M_o) of a pulse dose marker which would have occurred had the marker been instantaneously mixed with U_f and is computed from dose of M_i/M_o. M_o and kp are estimated by fitting the concentration of M/U _vs._ time postdose to the time-dependent, time-independent two-compartment model with time delay (Ellis _et al._, 1979 _Fed. Proc._ 38:2702). In this model, M_o corresponds to C_o and kp corresponds to λ_2.

Observed fecal output was 0.971 ± .03 of that predicted by the above pulse dose technique when applied to 23 sheep given a pulse dose of ^{144}Ce and feces collected at 6-hour intervals for 8 days. Good agreement between fecal output estimated by constant infusion and the pulse dose procedure was also obtained in 18 grazing animals when fecal samples were collected at 4, 8, 16, 20, 24, 28, 40, 48, 64, 72, 88, 96, 112, 120, 136 and 144 hours postdose. Indications are that adequate estimates of C_o and λ_2 and the other two parameters in the above model can be obtained from as few as seven fecal samples collected at 0, 16-18, 24, 36, 48, 60 and 72 hours postdose. Efforts are being directed to further reducing the number of fecal samples and maintaining accuracy through the use of models with fewer than four parameters and intercorrelation among parameters.

A REVIEW OF THREE METHODS TO ESTIMATE VOLUNTARY INTAKE OF GRAZING LIVESTOCK

By Samuel W. Coleman

Several different methods have been proposed to estimate intake by grazing livestock. These include water turnover (1), several fecal excretion estimating procedures, comparative feeding and gravimetric techniques. Fecal excretion estimation techniques are being discussed by other panel members; hence, this discussion will focus on comparative feeding and gravimetric procedures. A short description, to include advantages and assumptions, is given for each. Comparative precision is given by coefficients of variation (table 1).

COMPARATIVE FEEDING

It is generally recognized that when ruminants are offered forage alone, and in amounts of excess of consumption, their intake of digestible energy is a function of animal factors, environmental factors and forage composition factors. It is often difficult to separate effects of forage and non-forage factors influencing intake, especially so in the grazing situation when animal performance, i.e. average daily gain, is the only "quality" parameter which can be measured directly. It would be helpful, therefore, to be able to separate and quantify the effects of forage from non-forage factors.

The comparative feeding technique involves the use of a "reference set" of cattle similar in genetics, age and size to the ones grazing pasture. These are fed a known amount and quality of feed (preferably similar in digestible energy and protein content to the forage from the test pasture) which, it is anticipated, will provide gains similar to those of the grazing animals. Digestible energy intake per pound of gains should be approximately the same by each set of animals. If estimating dry matter intake is desired, one can divide digestible dry matter intake by forage digestibility. Lake et al. (6) used this technique to determine intake by steers on irrigated pastures. He further improved the technique by using monozygotic twins, assigning one of each pair to pasture and one to confinement. Daily gains, and thus presumably, digestible energy intake were very similar for both groups. Kromann et al. (5) also used a variation of this technique to verify the "fecal excretion procedure." Soilage from the pastures being grazed by one group of steers was also fed to a separate group of steers in dry lot. Garrett et al. (3) further estimated efficiency of conversion of feed by confined vs. grazing steers as the difference between digestible energy (TDN) intake (from hand feeding or fecal excretion procedures) and the digestible energy the steers should have consumed to produce their gain. Since more activity was noted in grazing animals, one would expect less efficient conversion of feed to gain of grazing steers when compared to confined steers. In this study there was little difference between the groups indicating similar efficiencies of conversion.

Some of the assumptions inherent in the technique include (1) similar efficiency of converting digestible energy to gain by confined and pastured

animals; (2) similar efficiency of conversion of the feed consumed in confinement compared to pasture material consumed.

A variation of this technique is presently being used in Oklahoma. Four levels of digestible energy are limit-fed to twelve groups (three replications of each level) of animals in confinement. Samples of the feed are analyzed for *in vitro* dry matter disappearance from which digestible energy will be estimated. Digestible energy intake is regressed on weight gain. Gain from the cattle on pastures is used to calculate their intake of digestible energy (figure 1). There are advantages of using this technique over simply calculating intake from gains using NRC requirements. These advantages inclue (1) removal of environmental factors associated with location, climate, temperature, etc., since both groups of cattle are fed in the same location at the same time and (2) removal of animal effects, since the confined animals are randomly selected from the same group as the grazed animals. Further, it has an advantage over one confinement group in that weight gains of pasture animals are bracketed within a known relationhsip; i.e. weight gain:digestible energy intake.

Little information could be found from which to arrive at estimates of variance for the comparative feeding technique.

EATING BEHAVIOR

Feed intake (I) by grazing animals is related to the time spent eating (T), the number of bites per unit of time (R) and the average size of each bite (S). Thus I = T x R x S (2). Few attempts have been made to estimate forage consumption in this way because of the difficulty in measuring each of these components. Recently methods of recording the number of bites and grazing time over extended periods have been developed (2, 9).

The technique to measure bite size consists of collecting samples of forage from an esophageal fistula over a given period of time. The number of bites are recorded (by observation or mechanically) during the grazing period and bite size calculated. Grazing time can also be monitored using mechanical recorders. It has been observed that bite size (and therefore grazing intensity) is not consistent (2). Therefore, to obtain correct intake values, it is essential that calculations be adjusted for variation in morning *vs.* afternoon grazing. Furthermore, prehension and mastication must be differentiated using separate bite counters for "head up" and "head down." Assumptions inherent in this technique include (1) complete recovery of grazed material via the fistula; (2) similar bite size during both sampling and non-sampling; and (3) accurate separation of prehension, mastication and rumination bites. Advantages include (1) it is a gravimetric technique; (2) a sample of grazed forage is available for subsequent chemical analyses; and (3) laboratory analysis is minimal when compared to that associated with marker techniques.

Chacon *et al.* (2) compared this technique with daily "before and after" yield measurements (sward sampling) of grazed strips (table 1). The large number of pasture yield samples is the factor limiting use of the "sward sampling" technqiue. Chacon *et al.* used 38 quadrats in uniform forage and measured coefficients of variation (CV) for dry matter intake of 11.2%. This was a large number of pasture samples; hence the CV is lower than those of most of the results in the literature (the majority of forage to be sampled is not very uniform). They found similar precision (10.1% CV) using the eating behavior technique. In absolute terms, from forage at 6, 7 and 8 weeks of regrowth, organic matter intake (OMI) was 7.19, 7.33 and 6.71 kg/animal/day using the

Table 1. Coefficient of Variation for Estimation of Intake

METHOD	C.V.%	REFERENCE
Sward Sampling	11.2-21.9	Chacon *et al.* (2) Walters and Evans (10)
Fecal Excretion	8.0-25.2[a]	Moran (8)
Forage Quality Index	N/A[b]	
Eating Behavior	10.2	Chacon *et al.* (2)
Animal Weight	10.4	McCartor (7)

[a] Concentration of Cr_2O_3 excreted.
[b] Not available.

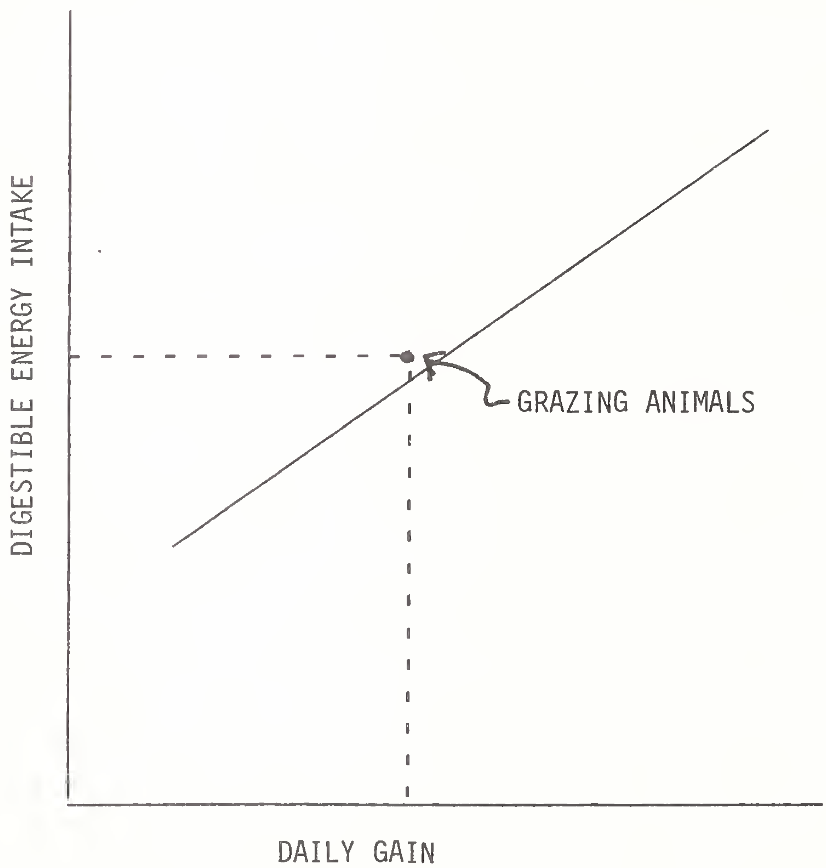

Figure 1. Use of the relationship between digestible energy intake and daily gain to determine intake of grazing animals.

"sward sampling technique." Using the best variation of the eating behavior technique, estimates of OMI were 7.20, 7.39 and 7.02 kg/animal/day.

ANIMAL WEIGHT

McCartor (7) reported a procedure for directly measuring intake of grazing animals by weighing the animal and determining the increase of weight before and after grazing. Water consumption was determined and its effect removed. Feces and urine were collected using a total-collection apparatus, and weighed with the animal. Due to volume of excreta voided, the apparatus had to be emptied at 4-hr intervals. The technique avoided many of the assumptions associated with other methods, especially fecal excretion methods, but is laborious and requires nighttime labor. Another significant disadvantage is that water vapor loss from lungs, skin and collection apparatus, as well as CO_2 loss from the lungs and rumen, cannot be determined.

Another technique, similar in purpose, was described by Horn (4). It overcomes some of the problems encountered by McCartor (7). The technique involves placing a load cell under each foot to continuously monitor weight of the animal. Electronic data collectors and radio transmitters are used to relay the weight to the laboratory to be logged by an operator or a computer. At present, the system must be manually operated through a "paging" signal but it could be operated by a timer to check and record weights at given intervals, e.g. one each minute. Assumptions include that (1) losses of urine and feces and gain due to water consumption can be detected and acounted for; (2) CO_2 and water losses from the lungs, skin and rumen are negligable or can be calculated; (3) equipment can be packaged ruggedly enough to withstand animal abuse; and (4) a forage sample representative of forage consumed can be obtained for chemical analysis (especially moisture).

McCartor (7) used one animal in a trial and obtained dry matter intake of $6.28 \pm .65$ kg over 5 days. At the present time, no comparative data is available on either animal weight methods.

CONCLUSION

Though considerable methodology research has been conducted to estimate forage intake of grazing animals, no one method has yet been proven to be superior. Coefficients of variation of existing tested methods are similar in magnitude and all have inherent assumptions. These assumptions are not universally accepted and, no doubt, are not equally valid under the different conditions over the world where forage is harvested by the animal and the amount harvested must be quantified.

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NEW RESEARCH AND NEW RESEARCHERS IN THE AREA OF PASTURE FORAGE UTILIZATION IN KENTUCKY, NORTH CAROLINA, VIRGINIA, SOUTH CAROLINA, GEORGIA AND TENNESSEE

By J. W. Holloway

I appreciate the opportunity to review the research in pasture forage utilization being conducted in Tennessee and bordering states. I also appreciate the aid that I received from Dr. Don Ely, Dr. Chuck Dougherty and Dr. Roger Henkin of Kentucky, Dr. Joe Burns of North Carolina, Dr. Joe Fontenot, Dr. Carl Polan and Dr. Roy Blaser of Virginia, Dr. Dee Cross of South Carolina and Dr. David Mertens, Dr. John Stuedeman and Dr. Don Burdick of Georgia. These people were my contacts from their respective states and provided me with information concerning research in their locations. I will discuss the research by state. This is not meant to be an exhaustive review but an overview of some of the newer research.

Kentucky. Research in Kentucky includes work concerning:

1. Availability of sulfur in fescue especially as related to conditions of high levels of molybdenum and nitrate.
2. Nitrate toxicity in highly fertilized fescue.
3. Relationship between lignification and digestion.
4. Use of melfluidide, a growth regulator, to prevent fescue from fruiting, thereby increasing nutritional quality.
5. Ovulation rate of sheep grazing alfalfa, bluegrass, white clover and birdsfoot trefoil.
6. Early establishment of alfalfa and clover in fescue.
7. Methods of maximizing yield and change in nutrient quality of stockpiled fescue.
8. Toxins associated with fescue, especially the relationship between loline and systemic fungi.

North Carolina. Research in North Carolina includes work concerning alteration in rumen fermentation, especially concerning methane inhibitors and methods of increasing nutrient bypass. Future work at Raleigh will be facilitated by new experimental facilities presently under construction. These facilities are a storage and processing unit and a rumen physiology unity.

Virginia. Research in Virginia includes work concerning:

1. Forage utilization systems involving systems for both cow-calf and growing-finishing.
2. Contribution of legumes in grass pastures.
3. Calf-marketing alternatives in conjunction with Oklahoma.
4. Pasture as the only forage source for dairy cattle.
5. Relationship between yield and quality of forage as explained by photosynthesis and respiration.

South Carolina. The research at South Carolina includes work concerning:

1. Virus-resistant white clovers.
2. Selection for high-producing cool-season grasses.
3. Backgrounding-finishing systems emphasizing year-round grazing.
4. Modeling for identification of research goals.

Georgia. The research at Georgia includes work concerning:

1. Modification of detergent system for better feedstuff evaluation.
2. Factors influencing kinetics of digestion, including factors related to particle size reduction, animal differences in rate of passage, stimulation of rumination and particle shape.
3. Mg containing boli for prevention of grass tetany.
4. Mechanisms involved in tetany.
5. Causes of necrotic fat in cattle grazing fescue.
6. Relationship between the fractions of cell walls and nutritive value.
7. Characterization of nitrogenous fractions of plants.
8. Extraction of proteins from legumes.
9. Formaldehyde-urea-lysings polymers for controlled protein digestion.
10. Near IR techniques of forage analysis.

Tennessee. Research in Tennessee includes work concerning:

1. Causes and prevention of grass tetany especially in the areas of seasonal changes in plant mineral composition, mineral utilization by lactating cows, pasture supplementation and treatment through high Mg enemas.
2. Selection of high-yielding orchardgrass varieties.
3. Genotype x nutritional environment interactions.

FECAL INDICES FOR PREDICTION OF GREEN FORAGE DIGESTIBILITY AND CONSUMPTION

By J. W. Holloway, R. E. Estell II and W. T. Butts, Jr.

SUMMARY

Thirty-nine in vivo digestion determinations with eight steers averaging 218 kg were made on green fescue and fescue-legume mixtures during the spring, summer and fall of 1979 in order to obtain an array of forage digestibility. Composite fecal samples were analyzed for dry matter (DM), N. ether extract (EE), crude fiber (DF), ash, cell wall constituents (CWC), acid detergent fiber (ADF), acid detergent lignin (ADL), acid insoluble ash (ALA), urobilinogen (UROB), in vitro DM digestibility (IVDMD), Na and Zn. Hemicellulose, cellulose, acid soluble ash (ASA) and nitrogen-free extract (NFE) were calculated. Fecal components related ($P<.10$) to DM intake (DMI) were: DM, N, CF, EE, NFE, ASA, IVDMD, CWC and Zn. The best (highest R^2) multiple regression equations for prediction of CMI, fecal DM output (FDMO), DMD and digestible DM intake (DDMI) had R^2 of .87, .60, .79 and .82, respectively. The respective residual standard deviations (RSD) for these models were: .33 kg/day, .17 kg/day, 6.04% and .38 kg/day. A relatively simple, usable model for predicting DDMI was: DDMI = -6.66 + 1.65 (N) + .37 (EE) + .08 (CWC) -.08 (DM) (R^2 = .74, RSD = .41 kg/day). The equation DDMI = -1.13 + 1.32 (N) had an R^2 of .44 and a RSD of .58 kg/day. Fecal N indices do not have broad application because the relationship between fecal N and forage intake or digestibility changes as season of year, N in forage and species consumed changes but the addition of EE, CWC and DM to models containing N overcomes to a large extent these problems.

INTRODUCTION

A limitation to nutritional research with grazing ruminants under extensive pasture conditions is that no reliable and simple technique for measuring ingestion or digestibility of forage ingested by undisturbed animals is available. Langlands (1975) summarized research in this area by stating, "Techniques available for studying the nutrition of grazing animals are characterized by relatively low precision, a high labour demand and a high sensitivity to bias." Possible the most important complicating factor involved in estimation of nutrition of grazing animals is that when given the opportunity, they select forage different than that available (Waite et al., 1951; Hardison et al., 1954; Arnold, 1960; Blazer et al., 1960; Spedding et al., 1966). Only one technique for the evaluation of nutritional status of grazing animals has potential for application under extensive pasture conditions. That technique is the fecal index. Fecal nitrogen and chromogen have been employed in indices, but equations that have broad application have not been developed because the relationship between fecal constituents studied and digestibility varies with species of pasture, season of year, level of intake, and extent

of nematode infection (Langlands, 1975).

Fecal matter, however, contains a large number of both endogenous and exogenous constituents other than those that have been employed in indices. No survey of the fecal constituents as to possible relationships with digestibility or intake has been reported. The purpose of this experiment was to evaluate a selected array of fecal constituents and to develop indices for predicting green fescue and fescue-legume forage digestibility and consumption by steers.

MATERIALS AND METHODS

Forage Harvest and Digestibility Trial Management. An array of forage digestibility was obtained by harvesting tall fescue (*Festuca arundinacea* Schreb.) and legumes (crimson clover, *Trifolium incarnatum*; red clover, *Trifolium pratense* L.; and Kobe lespedeza, *Lespedeza stipulacea* Maxim.) over the grazing season of 1978. These forages were mixed in proportions ranging from 100% fescue to 40% fescue and 60% legume and fed in 6 digestibility trials initiated on April 27, May 17, June 26, August 7, September 11 and October 16. The legume consisted of 1 cutting of crimson clover (April 27), 3 cuttings of red clover (May 17, June 26, August 7) and 1 cutting of Kobe lespedeza (September 11). In the trial of October 16 only fescue was fed. These forages were fed in green form *ad libitum* to Angus steers (average weight 218 kg) confined in digestion crates. These steers were also allowed *ad libitum* quantities of water and salt. Each trial consisted of a 7-day preliminary period and a 5-day total collection period. Fescue forage was harvested at about 0900 each day and fed fresh. Because of logistical problems, legumes were harvested at the initiation of each trial and frozen until thawed and fed. Between trials, the steers grazed pasture consisting predominantly of fescue and red clover. A total of 39 *in vivo* digestion determinations were made. Table 1 summarizes these data.

Fecal Analyses. Composite wet fecal samples were analyzed for dry matter (AOAC, 1975). Dried composited samples were analyzed for N, EE, CR and ash (AOAC, 1975) and for CWC, ADF and ADL by procedures outlined by Van Soest (1963). Na and Zn content were determined by atomic absorption spectrophotometry. IVDMD was determined by the technique of Tilley and Terry (1963). AIA was determined by the method of Van Keulen and Young (1977). Wet frozen fecal samples were thawed and analyzed for UROB by a technique (Method A) discussed by Schwartz and Bracho (1972). Hemicellulose, cellulose, ASA and NFE were also calculated.

These analytical procedures were selected to adequately describe fecal matter as to its undigested residue (CF, CWC, ADF, ADL, hemicellulose and cellulose); its endogenous fraction (UROB) and its partially endogenous, partially exogenous fraction (N, EE, ash, Na, Zn, AIA, NFE, IVDMD and ASA). A description of fecal composition is given in table 2.

Statistical Analysis. Stepwise regression procedures were employed to find the best models (maximum R^2) for explaining variation in the dependent variables: DM intake, fecal DM output, DM digestibility and digestible DM intake. Only the variables associated with characteristics of the feces were Included as independent variables. Linear and quadratic effects as well as all possible interactions of main effects were included in the independent variable list. When a quadratic effect or an interaction was important ($P<.05$), main effects were also included. All statistical analyses were perfor-

formed on the 39 determinations across all forage combinations.

RESULTS AND DISCUSSION

Relationships Among Fecal Components. Coefficients of simple correlation indicating relationships among fecal components are presented in table 3. These fecal components can be classified into three categories. These are: (1) N, EE, ash, ASA, IVDMD and Zn; (2) CF, NFE, ADF, CWC, cellulose, ADL and AIA; and (3) DM, UROB, Na and hemicellulose (table 3). The components of categories 1 and 2 are generallly positively related (P<.10) to components in the other category. Components of the third category are generally not related to other components regardless of category. In general, category 1 consists of soluble components that are at least partially of endogenous origin, and category 2 consists of insoluble components of exogenous origin, while category 3 is not definable. Of the components in categories 1 and 2, only NFE does not appear to fit. Although NFE contains lignin, it is generally considered to be soluble carbohydrate portion and composes a relatively large part of the feces. It is therefore, surprising that this component is positively correlated with components of the fibrous fraction of the feces. It is possible that this relationship is due at least partially to a part-whole relationship since NFE contains lignin.

It is also surprising that percentage CM of feces was not negatively correlated with measures of fibrousness since cattle grazing lush (low fiber) forages generally experience high rates of passage and low DM feces. UROB was positively related (P<.10) to Na (table 3) as was expected since UROB is the reduced form of bilirubin found in the feces (Gustafsson and Lanke, 1960) and a source of fecal Na is bile salts that are secreted along with bilirubin. The relationship (P<.10) between UROB and ADL is difficult to explain except by chance. Although Na was generally not related (P>.10, table 3) to other components, it was negatively correlated (P<.05) with CF and positively correlated (P<.10) with UROB as would be expected if Na includes a largely endogenous fraction. Hemicellulose was only correlated (P<.01) with components in which it was calculated and therefore, by definition, related to those components.

Relationships Between Measures of Intake and Digestibility and Fecal Components. Fecal components that were related (P<.10) to DM intake were usually also related (P<.10) to DM digestibility and digestible DM intake (table 4). There were two exceptions to this: ash and CWC were related (P<.10) to DM digestibility but not (P>.10) to DM intake. Only a few of the fecal components considered were correlated (P<.10) with fecal DM output: N, CF, ash, AIA, ASA, IVDMD, CWC and Zn (table 4). The fecal component that had the highest correlation (P<.01) with DM digestibility was N. This positive relationship is the basis of the fecal N index (Lancaster, 1949; Reid, 1952; Schneider et al., 1955; Kennedy et al., 1959; Langlands, 1975). The relationship (P<.01) between fecal N and estimates of forage intake, however, has not been reported.

A large proportion of fecal N is of metabolic origin (Blaxter and Mitchell, 1948). It therefore seemed reasonable that other fecal components that are at least partially of endogenous origin would be related to forage digestibility and intake. The components that are at least of partial endogenous origin selected for evaluation were EE (Maynard et al.,1979), UROB, IVDMD, Na (Perry et al., 1967) and Zn (underwood 1977). Of these, EE, IVDMD and Zn were positively related (P<.10) to DM digestibility, DM intake and digestible DM intake. At least a part of these relationships probably resulted from a relatively constant endogenous excretion of these components resulting in a negative

TABLE 1. DESCRIPTION OF INDIVIDUAL DIGESTION TRIALS

Date of Trial	Percent Legume 0 / Percent Fescue 100	10 / 90	20 / 80	30 / 70	40 / 60	50 / 50	60 / 40	Calf weight, kg x	SD	DM intake, kg/day x	SD	Fecal DM output, kg/day x	SD	DM digestibility % x	SD	Digestible DM intake, kg/day x	SD
April 27	2	0	2	0	2	0	2	189	19.3	3.7	.83	.8	.17	77.1	2.53	2.9	.69
May 17	2	1	1	1	1	1	1	182	18.3	2.3	.62	.8	.12	63.7	5.86	1.5	.51
June 26	1	1	1	0	0	0	1	204	21.7	2.1	.10	1.2	.10	42.0	3.46	.9	.08
August 7	2	1	1	1	1	1	1	236	18.6	3.1	.43	1.1	.17	64.2	4.39	2.0	.35
Sept. 11	2	1	1	1	1	1	1	259	16.5	3.4	.48	1.1	.18	67.4	1.92	2.3	.32
Oct. 16	3	0	0	0	0	0	0	247	8.2	2.5	.30	1.4	.44	50.0	13.11	1.2	.27
For a total of 39 determinations								218	35.2	3.0	.78	1.0	.24	64.0	11.26	1.9	.76

Table 2. COMPOSITION OF FECES[a]

Variable	Mean	SD	Minimum	Maximum
Dry matter (%)	16.46	2.178	12.20	21.20
N (%)	2.33	.383	1.66	3.00
Crude Fiber (%)	24.07	2.142	17.45	26.89
Ether Extract (%)	3.86	1.115	2.17	6.83
Ash (%)	13.95	1.801	11.30	17.94
Nitrogen free extract (%)	43.54	3.029	36.97	48.69
Acid insoluble ash (%)	.85	.276	.35	1.80
Acid soluble ash (%)	13.09	1.614	10.72	16.77
Urobilinogen (%)	2.81	1.232	.53	6.43
In vitro DM digestibility	24.31	6.987	5.34	42.18
Acid detergent lignin (%)	18.18	3.737	12.70	27.66
Acid detergent fiber (%)	44.39	7.848	18.71	57.58
Cell wall constituents (%)	58.67	3.815	48.86	65.87
Hemicellulose (%)	14.29	7.483	.00	38.22
Cellulose (%)	26.21	5.962	4.60	33.63
Na (mg/g)	1.11	.452	.34	2.10
Zn (mg/g)	.44	.178	.22	1.06

[a] All values except dry matter are on a dry matter basis.

TABLE 3. COEFFICIENTS OF SIMPLE CORRELATION OF FECAL COMPONENTS

	N	CF[a]	EE[b]	Ash	NFE[c]	AIA[d]	ASA[e]	UROB[f]	IVDMD[g]	ADL[h]	ADF[i]	CWC[j]	Hemi-cellu-lose	Cellu-lose	Na	Zn
DM	-.34*	-.13	.35	.00	.23	.14	-.02	-.10	-.12	.08	.11	.00	-.12	.10	.01	-.10
N		-.47**	-.02	.40**	-.69**	-.05	.45**	-.09	.56**	-.22	-.46**	-.60**	.15	-.44**	.14	.74**
CF			-.40*	-.44**	.07	-.22	-.46**	-.16	-.52**	.19	.14	.49**	.11	.06	-.36*	-.25
EE				.29†	-.24	.28†	.28†	.12	.51**	.16	.07	-.20	-.17	-.02	-.15	.12
Ash					-.70**	-.72**	.99**	-.20	.47**	-.48**	-.07	-.54**	-.21	.22	.02	.42**
NFE						-.33*	-.73**	.25	-.54**	.27†	.28†	.53**	-.01	.19	.19	.71**
AIA							.63**	-.14	.11	-.38*	.14	-.22	-.25	-.41**	-.09	.12
ASA								-.20	.50**	-.47**	-.10	-.57**	-.20	.18	.03	.45**
UROB									-.02	.30†	.06	.08	-.02	-.12	.28†	.22
IVDMD										-.15	-.16	-.53**	-.11	-.11	.09	.40**
ADL											.62**	.24	-.50**	.15	-.15	-.29†
ADF												.26	-.87**	.87**	-.13	-.52**
CWC													.25	.17	.20	-.63**
Hemicellulose														-.78**	.23	.20
Cellulose															-.07	-.47**
Na																-.15
Zn																

[a]Crude fiber. [b]Ether extract. [c]Nitrogen free extract. [d]Acid insoluble ash. [e]Acid soluble ash. [f]Urobilinogen. [g]*In Vitro* DM digestibility. [h]Acid detergent lignin. [i]Acid detergent fiber. [j]Cell wall constituents. †R=0, P<.10. *R=0, P<.05. **R=0, P<.01.

TABLE 4. COEFFICIENTS OF SIMPLE CORRELATION OF FORAGE DIGESTIBILITY AND INTAKE WITH FECAL CHARACTERISTICS

	Fecal Components																
Item	CM	N	CF[a]	EE[b]	Ash	NFE[c]	AIA[d]	ASA[e]	URON[f]	IVDMD[g]	ADL[h]	ADF[i]	CWC[j]	Hemi-cellu-lose	Cellu-lose	Na	Zn
DM intake	-.27†	.56**	-.35*	.37*	.23	-.47**	-.04	.26†	.00	.44**	.13	-.13	-.05	.10	-.24	.06	.34*
Fecal DM output	.19	-.27†	.35*	.05	-.35*	.16	-.29†	-.34*	-.12	-.34*	.22	.04	.51**	.22	.19	-.20	-.30†
DM digestibility	-.35*	.67**	-.54**	.28†	.35*	-.46*	.08	.37*	.17	.58**	.04	-.14	-.42**	-.08	-.20	.23	.47*
Digestible DM intake	-.33*	.66**	-.47**	.36*	.34*	-.53**	,95	,38*	,94	,56**	.06	-.14	-.21	.04	-.22	.12	.44*

[a]Crude fiber. [b]Ether extract. [c]Nitrogen free extract. [d]Acid insoluble ash. [e]Acid soluble ash. [f]Urobilinogen. [g]*In Vitro* DM digestibility. [h]Acid detergent lignin. [i]Acid detergent fiber. [j]Cell wall constituents. †R=0, P<.10. *R=0, P<.05. **R=0, P<.01.

relationship (P<.10 for N, IVDMD and Zn) between endogenous components and fecal DM output. The relationships between EE and DM intake and digestibility were possibly due to some factor other than the endogenous component of EE, because EE was not (P>.10) related to fecal DM output. Other possible reasons for the relationship between Zn and DM digestibility would possibly be that legumes are generally higher in Zn than are grasses (Thomas, 1952), mature forages generally have lower Zn concentrations than immature forages (Underwood, 1977) and Zn absorption is limited under conditions of rapid rates of passage (Underwood, 1977).

Fecal ash and ASA were also related (P<.05, table 4) to fecal DM output, DM digestibility and digestible DM intake. The patterns of relationships were similar to those noted for the fractions of partial endogenous origin (N, IVDMD, Zn) and were possibly due to an endogenous ash fraction. Also, UROB, because of its completely endogenous nature, was expected to be related to DM digestibility and intake in a similar manner as that of other components of at least partial endogenous origin. Bilirubin (the precursor of UROB) excretion is controlled in several ways. First, it is the metabolic product of heme metabolism and its excretion is therefore related to red blood cell volume and turnover. Second, it is excreted with the bile and therefore enters the tract in proportion to the EE content of the digesta, and its excretion is controlled at the endocrine level (secretin control over bile flow, Cable and Heath, 1975). However, UROB was not correlated (P>.10) to either DM digestibility or intake (table 2). Perhaps the failure to detect these relationships was due to the large amount of error associated with estimation of UROB (c.v. = .438, Schwartz and Bracho, 1972).

Two estimates of fecal fiber (CF and CWC) were negatively related (P<.01) to DM digestibility. This is in agreement with results of Richards _et al._, (1958), Jarrige (1966) and Vera (1973). Vera (1973), however, reported higher correlations than those obtained in this experiment. The negative relationships between DM digestibility and CF and CWC were possibly due to the higher concentration of these fractions in forage of lower digestibility resulting in increased concentrations (P<.05) in the corresponding feces. Thus, increasing concentrations of CF or CWC were associated with a decrease in DM digestibility (table 4). Fecal CF content was also negatively correlated (P<.05, table 4) with DM intake and digestible DM intake. Similar to the results of Vera (1973), low correlations (P>.10, table 4) between ADF and forage digestibility were noted. Vera (1973), however, reported a positive correlation (r = .77) between ADL and DM digestibility for weeping lovegrass (_Eragrostus cruvula_) during the spring season. No relationship, however, was detected (r = -.14, P>.10) in this experiment, possibly due to a wider variation in forage quality included in this experiment, as compared to that of Vera (1973). Richards _et al._, (1958) also reported low correlation between fecal lignin and DM digestibility.

Fecal NFE content was related (P<.05) to forage digestibility and intake in a similar pattern as that noted for CF and CWC. The carbohydrate fractions (other than the calculated cellulose) that contained soluble fractions were more closely related to forage intake and digestibility than the relatively insoluble ADF and ADL components.

Fecal DM was also related to DM digestibility and intake as would be expected, since increased rates of passage are associated with reduced DM content of the feces.

Prediction of Forage Nutritive Value from Fecal Components. Models for

predicting DM intake, fecal DM output, DM digestibility and digestible DM intake are shown in tables 5, 6, 7 and 8, respectively. For comparison purposes, simple linear models using N as the only independent variables are shown first in these tables. The remaining models in each table are arranged in order of complexity from the best (highest R^2) one-variable model to the best ten-variable model.

Prediction of DM Intake. The best single variable prediction equation contained N (model 1, table 5). As indicated by the relatively low R^2 (.3151) and relatively high residual standard deviation (RSD = .66 kg/day), this equation is not very useful for predictive purposes. The addition of EE and CWC to this model substantially increased the usefulness of these prediction equations increasing R^2 to .7039 and decreasing RSD to .45 kg/day (model 4, table 5). Models of greater complexity contained quadratic terms for N ($P<.05$), Na ($P<.01$) and interactions of Na with CWC ($P<.01$) and with EE ($P<.05$). The model of best predictive power contained 10 independent variables (model 10, R^2 = .8719, RSD = .33 kg/day, table 5).

Prediction of Fecal DM Output. Models for prediction of fecal DM output were not as useful as those for prediction of DM intake having small R^2 and relatively larger RSD (tables 5 and 6). The best one-variable model contained CWC as the independent variable (model 2, R^2 = .2578, $P<.01$, table 6). More complex models contained the significant terms: Na ($P<.01$), DM ($P<.05$), NFE ($P<.0$), AIA ($P<.01$), CF ($P<.10$), Zn ($P<.10$) as well as CWC ($P<.01$). The best prediction equation, however, only accounted for 59.66% of the variation of fecal DM output.

Prediction of DM Digestibility. As would be expected from the above discussion, the best one-variable model for prediction of DM digestibility contained N as the independent variable (model 1, table 7). This model, however, explained only 45.34% of the variation in DM digestibility, possibly because of different relationships between fecal N and DM digestibility for different seasons of the year (Langlands, 1975). Almost 20% of the variation not explained by this model was explained by the addition of linear terms for EE ($P<.01$), DM ($P<.01$) and Na (model 4, $P<.01$, table 7). Apparently, the addition of these variables to the model containing N accounted for some of the difficulties experienced by many researchers in the application of the fecal index technique (Lambourne and Reardon, 1963; Langlands, 1967; Langlands, 1969; Young and Corbett, 1972; Langlands, 1975). Equation 4 in table 7 has broader application than others previously reported. The average miss ($Sy \cdot x$) of this equation in a range of DM digestibility of from 35.1 to 80.0% (table 1) was 2.49 percentage units. The average miss of the best 10-variable model (model 10, table 7) was 1.28 percentage units. Na was not highly correlated with DM digestibility ($r = .23$, $P>.10$, table 4) but apparently can explain a significant amount of variation when combined with N, EE and DM in prediction equations. Of the variable of consistent significance in the models shown in table 7, all have an endogenous component. In the more complex models in table 7 (models 9 and 10), Na x DM interaction explained an important ($P<.01$) amount of variation.

Prediction of Digestible DM Intake. As would be expected, the best one-variable model contained N as the independent variable. This model, however, did not precisely predict digestible DM intake, explaining only 44.05% of the variation (model 1, table 8). Addition of EE, CWC and DM to N as independent variables increased the R^2 by 30 percentage units and decreased the RSD by .17 kg digestible DM/day (model 4, table 8). The average miss of this model

was .11 kg digestible DM/day. The only other variables that explained important (P<.10) sources of variation in more complex models were ADL, CF and NFE. The best model for prediction of digestible DM intake had an average miss of .07 kg digestible DM/day (model 10, table 8).

This research indicates that fecal N indices could not be developed that could adequately predict forage digestibility or intake of calves consuming fescue and mixtures of fescue and legumes throughout the growing season. The addition of other fecal components to the fecal N index, however, considerably improved the utility of the index. As a result, it appears that within the range of these data, the fecal indices developed could be utilized to estimate forage digestibility and intake of calves grazing fescue and fescue-legume pastures. These data also indicate that other multiple indices of broad application can be developed.

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TABLE 5. REGRESSION COEFFICIENTS AND ESTIMATES OF PRECISION FOR MODELS PREDICTING DM INTAKE

Model No.	Model	R^2	RSD[a]
1	.28 + 1.15 (N**)	.3151	.66
2	-.78 + 1.16 (N**) + .26 (EE**)	.4569	.59
3	-10.36 + 1.92 (N**) + .36 (EE**) + .13 (CWC**)	.6859	.46
4	-8.76 + 1.77 (N**) + .39 + .11 (CWC**) - .06 (DM)	.7039	.45
5	-9.79 + 1.91 (N**) + .38 + .13 (CWC**) - .05 (DM) - .01 (Hemicellulose)	.7177	.45
6	-10.56 + 2.02 (N**) + .37 (EE**) + .15 (CWC**) - .04 (DM) - .01 (Hemicellulose) - .19 (Na)	.7274	.45
7	-18.65 + 2.30 (N**) + .31 (EE**) + .16 (CWC**) - .39 (Na†) + .07 (NFE) + .04 (ADL†) + .18 (ASA*)	.7454	.44
8	6.12 - 3.98 (N) + 1.3127 (N^2*) - .33 (EE) - .07 (CWC) + .0201 (EE x CWC) - 6.20 (Na*) + .1288 (Na x CWC**) - .4328 (Na x EE*)	.8203	.37
9	7.44 - 2.30 (N) + 1.0600 (N^2) + .31 (EE**) - .01 (CWC) - 10.45 (Na**) + .1713 (Na x CWC**) - .47 (ash) - 13 (ADF) + .0116 (Ash x ADF)	.8333	.37
10	-9.19 - 4.54 (N) + 1.48 (N^2*) + .59 (EE) + .21 (CWC) - 9.24 (Na**) + .1735 (Na x CWC**) - .3776 (Na x EE*) + .55 (Cellulose) - .0096 (Cellulose x CWC) + .0054 (Cellulose x EE)	.8719	.33

[a] Residual standard deviation
† $P < .10$
* $P < .05$
** $P < .01$

TABLE 6. REGRESSION COEFFICIENTS AND ESTIMATES OF PRECISION FOR MODELS PREDICTING FECAL DM OUTPUT

Model No.	Model	R^2	RSD[a]
1	1.40 - .17 (N)	.0755	.23
2	-.86 + .03 (CWC**)	.2578	.21
3	-.91 + .04 (CWC**) - .16 (Na*)	.3508	.20
4	-.82 + .04 (CWC**) - .18 (Na*) - .01 (Cellulose)	.3966	.19
5	-1.21 + .04 (CWC**) - .18 (Na*) - .01 (Cellulose†) + .02 (DM†)	.4436	.19
6	-.51 + .04 (CWC**) - .16 (Na*) + .03 (DM*) - .03 (NFE†) - .28 (AIA*)	.5015	.18
7	-.21 + .05 (CWC**) - .21 (Na*) + .03 (DM*) = .03 (NFE*) - .31 (ALA*) - .02 (CF)	.5191	.18
8	.75 + .05 (CWC**) - .21 (Na*) + .03 (DM*) - .04 (NFE*) - .35 (AĪA**) - .03 (CF) - .01 (<u>In vitro</u> DM digestibility)	.5407	.18
9	2.33 + .04 (CWC**) - .21 (Na**) + .03 (DM**) - .06 (NFE**) - .41 (AIA**) - .04 (CF†) - .01 (<u>In vitro</u> DM digestibility) - .42 (Zn)	.5733	.18
10	2.66 + .04 (CWC**) - .23 (Na**) + .04 (DM*) - .06 (NFE**) - .38 (AIA**) - .04 (CF†) - .01 (<u>In Vitro</u> DM digestibility) - .57 (ZN†) - .01 (ADF)	.5966	.17

[a] Residual standard deviation

P<.10

* P<.05

** P<.01

TABLE 7. REGRESSION COEFFICIENTS AND ESTIMATES OF PRECISION FOR MODELS PREDICTING DM DIGESTIBILITY

Model No.	Model	R^2	RSD[a]
1	17.84 + 19.78 (N**)	.4534	8.43
2	6.16 + 19.94 (N**) + 2.93 (EE*)	.5376	7.86
3	33.50 + 17.09 (N**) + 3.91 (EE**) - 1.49 (DM*)	.6010	7.41
4	31.22 + 15.88 (N**) + 4.35 (EE**) - 1.65 (DM*) + 5.52 (Na*)	.6472	7.07
5	34.45 + 16.52 (N**) + 4.11 (EE**) - 1.69 (DM**) + 6.49 (Na*) - .29 (Hemicellulose)	.6821	6.81
6	54.41 + 14.32 (N**) + 3.91 (EE**) - 1.79 (DM**) + 7.25 (Na*) - .53 (Hemicellulose) - .38 (Cellulose)	.6917	6.81
7	3.38 + 14.87 (N*) + 4.47 (EE**) = 2.00 (DM**) + 7.03 (Na*) - .36 (Hemicellulose) + 15.15 (Zn) + .74 (NFE)	.7053	6.76
8	59.61 + 9.31 (N) + 2.54 (EE†) - 1.98 (DM**) + 5.85 (Na†) + 14.01 (Zn) + 5.64 (AIA) + .89 (ADL*) - 1.17 (CF)	.7209	6.69
9	-151.53 + 28.38 (N**) - 3.29 (EE) + 4.51 (DM*) + 95.90 (Na*) - .24 (ADF) + 1.58 (NFE) + .1563 (EE x ADF) - .2030 (Na x NFE) - 5.1399 (Na x DM**)	.7675	6.21
10	-244.28 + 92.57 (N*) - 2.24 (EE) + 4.69 (DM*) + 112.72 (Na*) + 1.88 (NFE) - .19 (ADF) + .1378 (EE x ADF) - .5392 (Na x NFE) - 5.2561 (Na x DM**) - 13.6294 (N^2)	.7876	6.04

[a] Residual standard deviation

† P<.1

* P<.05

** P<.01

TABLE 8. REGRESSION COEFFICIENTS AND ESTIMATES OF PRECISION FOR MODELS PREDICTING DIGESTIBLE DM INTAKE

Model No.	Model	R^2	RSD[a]
1	-1.13 + 1.32 (N**)	.4405	.58
2	-2.15 + 1.33 (N**) + .26 (EE**)	.5806	.51
3	-8.94 + 1.87 (N**) + .32 (EE**) + .09 (CWC**)	.7026	.43
4	-6.66 + 1.65 (N**) + .37 (EE**) + .08 (CWC**) - .08 (DM*)	.7414	.41
5	-7.90 + 1.82 (N**) + .36 (EE**) + .10 (CWC**) - .08 (DM*) - .02 (Hemicellulose)	.7624	.40
6	-6.41 + 1.69 (N**) + .33 (EE**) + .10 (CWC**) - .08 (DM*) - .02 (Hemicellulose) - .05 (CF)	.7730	.39
7	-6.29 + 1.49 (N**) + .31 (EE**) + .11 (CWC**) - .09 (DM†) - .02 (Hemicellulose†) - .07 (CF) + .66 (Zn)	.7796	.40
8	671.48 - 40.91 (N) - 6.52 (EE) + .09 (CWC**) - .9 (DM*) - 6.83 (CF) - 6.79 (NFE) - 6.70 (Ash) + .05 (ADL*)	.8026	.38
9	676.73 - 41.21 (N) - 6.59 (EE) + .10 (CWC**) - .08 (DM*) - 6.91 (CF) - 6.85 (NFE) + 6.75 (Ash) + .05 (ADL*) - .14 (Na)	.8064	.38
10	772.24 - 47.55 (N) - 7.58 (EE) + .10 (CWC**) - .10 (DM*) - 7.86 (CF†) - 7.80 (NFE†) - 7.70 (Ash) + .07 (ADL*) + .87 (Zn) + .01 (<u>In Vitro</u> DM digestibility)	.8155	.38

[a] Residual standard deviation

P<.10

* P<.05

** P<.01

METHODS TO DETERMINE OR ESTIMATE VOLUNTARY INTAKE IN GRAZING LIVESTOCK

By J. C. Burns and R. D. Mochrie

Determining the intake of dry matter by ruminants and its subsequent digestibility is critical in estimating the feed potential of any forage. Unlike stall-fed animals, the grazing animal has more opportunity to pick and choose and select a diet that differs appreciably from the composition of the overall available forage. Consequently, valid estimates of dry matter intake and quality of the forage consumed are extremely difficult to obtain in a grazing situation. Yet, such measurements are essential if the potential of forage is to be estimated.

We conducted a series of studies to measure the daily dry matter intake of grazing heifers. In all cases, animals were restricted to specific areas. The areas grazed were varied from study to study as were the areas used to estimate dry matter intake. Measurements were similar in all studies. Daily dry matter intake was determined using clipping strips, pre- and post-grazing. Forage was sampled to make quality estimates. Additional samples were taken to determine leaf:stem ratios and to determine short-period forage-regrowth rates.

In the first experiments, animals were confined to moveable cages to restrict grazing and to simulate conventional stall feeding, i.e., offering the animal as uniform a ration as possible. Levels of available Coastal bermudagrass were maintained at 3.8, 7.6 and 12.7 cm by clipping on one set of plots or by free grazing animals in another. Each pasture was marked off into four strips. Five fresh cage settings were made each day. This represented the length of each strip. At the beginning of the second day, the cages containing the animals were moved to the second strip and again five fresh cage settings were made. In the clipped pastures, the forage was cut every other day, resulting in three-day regrowth being offered to the caged animals. This procedure allowed rather uniform forage to be offered to the individually caged animal. The cages (5.5 x 4.9) contained an area of 26.9 m^2. A strip (1 m^2 area) was used to estimate dry matter intake. Intakes were estimated and forage was characterized each week for several cage settings on the day of sampling. The study was initiated in late May and continued through August.

A second series of experiments estimated the daily intake of two to three grazing animals confined on the average of 167 m^2/head. Several paired, adjacent pre- and post-grazing strips were harvested and sub-strips pooled in various patterns for comparisons. The areas used to estimate intake ranged from 4 to 18 m^2. These sub-strips totaled from 2.4% to 21.7% of the area grazed. Estimates of available dry matter pre- and post-grazing were also made with the nondestructive capacitance meter and compared to the clipped results. This experiment provides data on how the area harvested and the pattern of the harvested area altered the precision.

A third series of studies was conducted to estimate the combined daily intake of two grazing animals. An 85.2-m^2 area was harvested for the pre-estimate and a comparable area of 85.2 m^2 was grazed and then completely harvested post-grazing. In these studies, available forage was maintained at 3.8 and 12.7 cm. As previously, available forage levels were maintained by clipping for one set of pastures and by using free-grazing animals for the other. Estimates of intake were taken two or three times during the summer. Dry matter estimates were also obtained pre- and post-grazing using a capacitance meter, and compared with the clipping data.

These experiments represent a combination of approaches of indirectly measuring dry matter intake over a range of available forage levels. The size of areas grazed and sampled was increased in an attempt to overcome the inherent variation in available forage. The use of the capacitance meter allowed nondestructive estimates pre-grazing so that the identical area could be measured again post-grazing. The data have not been fully evaluated for the potential of these methods to estimate intake of grazing animals. Complete analyses will provide insight into the magnitude of variation in measuring intake of free grazing animals relative to sample size and number. Also, an evaluation of the capacitance meter as a potential tool in such studies will be made.

TRANSFER OF PRINCIPLES IN GRAZING EXPERIMENTATION TO FORAGE-ANIMAL DEMONSTRATIONS

By J. C. Burns

The final steps in forage evaluation must include estimates of both the quality and productivity of the forage under consideration. By necessity, this includes estimates of both animal performance and the forage productivity associated with the particular method of utilization that fits the producer's enterprise (such as grazing or hay or green chop or silage).

FORAGE COMPARISONS IN GRAZING SITUATIONS

The complexity of fairly evaluating forages in grazing situations essentially limits such efforts to formal grazing experiments. This complexity is contained in the nature of both the animal and forage and in the interrelationship relative to the decision and accomplishment of trying to measure either the animal potential or the pasture potential. If the former is evaluated, excess forage may be present and the yield potential of the forage underestimated. If the pasture potential is realized through proper utilization, then the animal potential may not be achieved.

Fair comparisons must permit consideration of both potentials arising through plant-animal interrelationships (1, 2). This requires specifically designed experiments that consider the appropriate animal type, pre-trial condition and animal number per pasture treatment, as well as appropriate pasture characteristics, grazing pressure, and other measurements. This is followed by statistical comparisons between or among treatments based on animal and pasture variation. Even in well-designed experiments, the precision desired is often difficult to achieve and investigator bias, including untimely decisions, can become important factors.

PURPOSE OF FORAGE-ANIMAL DEMONSTRATIONS

The notion that forage-animal demonstrations are desirable can be easily rationalized, and in fact, a series of such demonstrations can be easily planned. However, it is far more difficult to properly carry out such plans to assure that the data obtained are interpretable.

The purpose of a demonstration, as perceived by the investigator(s), is a very important element in its design and use. Complete agreement among either extension specialists or among researchers regarding the appropriate use of demonstration would probably be difficult to achieve. Yet, certain questions seem worthy of consideration relative to the use of demonstrations. In fact, it is desirable that investigators come to agreement upon certain points prior to initiation of a demonstration. Seven areas worthy of consideration are shown in Table 1.

Clearly, forage-animal demonstrations should be used to show producers

Table 1. Statements to help arrive at the purpose of forage-animal demonstrations

Use of Demonstrations	Response No	Response Yes	Degree of Complexity[1/]
To demonstrate:			
1) Quality difference in forage	X	--	--
2) Seasonal differences in quality	X	--	--
3) Animal variation in ADG	X	--	--
4) Animal health practices	X	--	--
5) Proper management and utilization of forage	--	X	I
6) Combination of 4 and 5	--	X	II
7) Potential productivity (kg/ha) of a grazing situation			
a) A component of a system	--	X	III
b) A year-round system	--	X	III

[1/] I = least complex, major interest is in forage and no animal measurements taken; II = intermediate complexity, major interest is in forage with animal thrift and reproduction of concern; and III = most complex involving gain per animal per unit area in addition to pasture measurements.

a practice that has already been found feasible through formal experimentation. They should highlight principles of forage and animal management, and be kept simple and specifically for the purpose intended. Consequently, points 1, 2, 3 and 4 in Table 1 should not be in question. One might argue point 2, i.e., seasonality of forage quality; however, proper resolution of this question involves a degree of complexity that should not be attempted. This problem, if serious, will manifest itself in the component part or in the year-round results.

Frequently, investigators believe that demonstrations are fruitful only if they terminate in an estimate of animal product per unit of area. However, realization that the major factor controlling animal product per unit of area, in practice, is probably digestible dry matter intake (DDMI) (assuming good animal health and good forage stands) and realization that forage available and its degree of utilization mainly control DDMI leads one to discover that a well-conceived demonstration that highlights item 5, Table 1, may furnish the missing key in producer education. Such studies can be achieved through timely grazing of small fields (possibly as little as two to three acres) of each forage that serves as a component of a year-round system, thereby providing a visual aid to education. This might be the most efficient expenditure of both labor and funds. In this case, no animal data are collected (Type I complexity, Table 1), but animals would be used as harvesters to maintain proper quantities of available forage. Pasture measurement, so important in understanding good utilization practices, should be stressed. However, such studies lack the excitement that seems associated with obtaining response per animal and per unit of area.

Item 6, in Table 1 combines good animal health and forage management practices on a farm scale, and if needed, allows for the periodic incorporation of more land area into the demonstration. In this case, gain per animal is obtained (assuming that the forage on the extra area, if different, is grazed only a short period and contributes only a small portion of the total days grazed) and forage management and utilization practices can be clearly demonstrated.

Demonstrations that include gain per animal and per unit of area (Point 7, Table 1) are probably the most desired from the producer's standpoint of acceptance and provide the best information for extension agents' purposes of education (presentations). However, focus should be on the management decisions that permitted the responses obtained. Demonstrations of Type III complexity also require the most investment in terms of investigator(s) time, additional labor and initial cost.

MINIMAL MEASUREMENTS REQUIRED

The conduct of formal grazing experiments are extremely costly both in terms of initial cost and in investigators' time and supplemental labor during the trial. Appreciable cost is also inherent in the conduct of worthwhile forage-animal demonstrations, yet it can be partially reduced by minimizing the measurements taken.

The complexity of the demonstration as determined by its purpose (Table 1) and the subsequent use of results will, to some extent, determine the measurements required. However, experience from formal experimentation provides a basis for suggesting minimal measurements needed for both the forage and animal components.

Forage Measurements

Data are needed for at least those areas listed below and each on a per-pasture (field) basis.

1) Botanical composition--Visual estimates are adequate in most cases and should be obtained at least in the spring, summer and mid-fall.
2) Determine grazing pressure (forage available per animal per day)--This measure permits an understanding of how pastures were grazed and can be extremely helpful in understanding animal response. It should be determined as frequently as possible. At least two estimates should be obtained per pasture. Estimates of available forage can be obtained by taking mower strips, by using nondestructive methods such as the disk blade or capacitance meter or simply by forage height. The latter method is easily taken and easily understood by producers and it should not be overlooked. An estimate of pasture productivity is also informative and can be obtained using caged areas; however, this is a costly addition.
3) Visual ratings of relative pasture integrity--An assessment of the nature of the pasture regarding plant cover and general stand health may be advantageous where stand persistence poses a problem. This measure can be easily obtained in the spring, summer and fall by simply scoring the stand 1 through 10.
4) Records of management inputs--Much is to be gained by detailed recordings of lime, fertilizer, seed and pesticide inputs, including dates of each event, quantity involved and cost. Also included should be grazing sequences, dates of grazing and clipping regimes.
5) Surplus forage estimates--Forage removed as hay or left as surplus should be accounted for. This might be handled as a separate category or converted to animal days or some similar conversion depending on the demonstration.

Animal Measurements

The areas for which individual animal measurements are needed follow.

1) Animal size (weight)--Each animal must be weighed at least at the initiation and at the end of the grazing period. This permits calculation of gain per animal. Several intermediate weighings would be valuable. If productivity of a specific pasture is of interest, then weights must be obtained for that pasture at the initiation and termination of each grazing period.
2) Animal type--The breed and general conformation of each animal should be recorded.
3) Animal condition--A relative animal condition score reflecting degree of finish should be determined at the initiation and termination of the grazing period. Records of the pre-grazing history are also essential since it can greatly alter subsequent animal gains.
4) Animal management practices--Detailed records concerning animal health practices, animal behavior and reproduction status are essential. Records should include the practice, the date used, cost involved and any problem areas.

SCOPE OF DEMONSTRATIONS AND POINTS OF FRUSTRATION

Logically, demonstrations should be uncomplicated and kept simple. The term "demonstrate" means to show by example. Consequently, complicated details should have been previously evaluated in formal grazing trials.

Scope of Effort

It follows, then, from the section above on the purpose of demonstrations and from the preceding statement that demonstrations should focus on displaying principles of grazing and animal management for portions of the grazing season, or select combinations of best components to form a year-round feeding system.

This allows for the interjection of previously evaluated innovative aspects of management such as creep grazing, early weaning, and first and second grazers and various combinations of storing feeds (hay, silage and stockpiling) preceded or followed by grazing. Discouraged are demonstrations that have a comparative element.

The frequent decision to develop demonstrations that compare the best possible system with the producer's present system and level of management is tempting, and in theory, reasonable. However, implicit in such a comparison is the assumption that both systems are <u>fairly</u> evaluated. Such demonstrations are no longer simple and interpretation of the results is complicated (see later). The inclusion of several treatments (plant or animal) presents the same problem and are probably best left for controlled grazing experiments.

Points of Frustration

Demonstrations are conceived, designed, initiated and conducted by a small group of people. These people generally generate their own source of frustration. Four such areas are mentioned below.

Probably the major consideration in assuring a successful demonstration, and on the other hand, the possible avoidance of the main point of frustration, is the selection of the "right" producer and extension agent cooperators. It is essential to find individuals who can see more than there own side of an issue and who are sufficiently dedicated to follow the plans and agreed upon procedures. Individual decisions and breakdown in communications means sure frustration.

Strong leadership in the design of the demonstration, allowing the full potential of the system to be realized without regard to fluctuating economics, is a critical need. This leadership must come from the agronomist and animal scientist involved in the basic design. Continual changes following the volatility of prices will frustrate all.

The third point of frustration revolves around the lack of timely decisions. Strong leadership is needed in the conduct of the study. The responsible individual(s) (probably the extension agent cooperator) to make either or both plant and animal decisions must see the demonstration often (weekly). Also, the producer cooperator must be in good communication with the extension cooperator when plant or animal changes occur that appear to need management decisions that have not yet been met. It is also important to have strong leadership regarding the termination of a demonstration. Even the best laid plans and intentions go awry. When this happens, all parties

become frustrated and it is best to terminate the study, salvaging what is of value up to that point.

The fourth point of frustration to be considered is that of data interpretation. If the investigators realize at the outset that they will simply demonstrate a set of principles in the form of a forage-animal component, or of a set of components in a series to form a system, which yields a certain biological or economic result and no more, then their frustration should be minimal. However, if they attempt to make comparisons by making biased research conclusions and believe that a component or the system under study is definitely superior or inferior to other unreplicated segments or systems (treatments) within the same unreplicated demonstration or in comparing results with independent studies, then their frustration level will be elevated because many will not agree.

The inclusion of several treatments in a system or the comparison of several systems within a demonstration leads to such expressions as "system A was not as improved as system B"; "system A provides an increase over the control"; "the biggest increase"; "the largest return"; "a significant improvement over the control," etc. These expressions are all inappropriate since they imply statistical significance.

Although replication might be achieved over years and/or from multiple locations using identical treatments, extreme caution must be exercised since statistical comparisons carry many subtle implications, one of which involves unbiased evaluation of each pasture in the study.

POTENTIAL MERIT OF FORAGE-ANIMAL DEMONSTRATIONS

Because of the high cost of large-scale grazing experiments and the large land area required to conduct total systems research, the component approach is frequently used. Such data are extremely valuable, but the components need to be put into proper sequence and evaluated for a year-round system. The controlled demonstration is perhaps one of the best ways to combine components (based on previous results) into a year-round system and get them into practice by the producer. This also allows for the introduction of innovative concepts when appropriate.

This approach brings together the producer, the extension specialist and the researcher. Each has a vested interest in terms of something to be gained from a well-conducted study or much to lose if the demonstration is poorly done. This joint involvement, with perhaps the inclusion of economists and farm management personnel, can result in newly found appreciation in several areas. These are 1) the importance and reward of good communication; 2) the realization of research gaps in planning and conducting the demonstration; 3) the realization that research results can apply to on-farm situations; 4) the importance of timely plant and animal management decisions; 5) the magnitude of the buffering capacity inherent in the plant and animal component of the producer's total enterprise and 6) the valuable training experience for the extension specialist and others involved.

Obviously the benefits delineated above can only be fruitful if studies are well conceived and conducted with controlled plant-animal management that permits the potential of the system to be expressed.

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